Creativity@School: mobile learning environments involving remote labs and E-Portfolios. A conceptual framework to foster the inquiring mind in secondary STEM education

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"*Creativity is a game of making and testing hypotheses, taking them as far as they can be taken, then watching them crumble and wondering why*" [1].

1. **Introduction**

"The science laboratory has been considered one of the main vehicles for enhancing science learning not only as a means of demonstration but also as the heart of the science learning process. Using inquiry provides students with the opportunity to engage in the process of investigation" [2]. In addition to promoting inquiry, the science laboratory can help students to acquire higher-order cognitive skills such as critical thinking, applying, synthesizing, decision making, and creativity [3]. Fostering and encouraging creative thinking while learning may not only breathe life into what is learned but can also deepen students' understanding and creative self-efficacy [4]. To that end, laboratory learning should be based on the constructivist learning approach in general and inquiry in particular [2]. This is because students need to come up with their own unique examples, uses and applications to develop an understanding of what they are learning: "formal education could benefit from the emphasis on personal involvement with ideas, open-style learning environments, and broad diversity among collaborating learners" [5].

Moreover, to support personal involvement and creative thinking, 'writing' can be an efficient means for reflecting, clarifying and systematizing ideas as well as ultimately for constructing understanding. Laboratory reports in particular are an integral part of science courses [6]. In this respect, innovative ICTs can provide novel opportunities to support a student's personal learning process documentation and to develop science writing competencies involving learner-generated multimedia content of laboratory experiences and field work.

Three current trends in ICT-based learning technology development are clearly recognizable at the current time to support creative STEM education: remote labs (1), personal learning environments (2), and portable devices (3):

- The experience of remote labs and tele-operated experimentation [7], [8] can be delivered to the learner by technically and didactically integrating the labs into collaborative learning systems like monolithic learning and content management systems (LCMS), or cloud-based personal learning environments (PLE).
- PLEs are "educational technology which can respond to the way people are using technology for learning and which allows them to shape their own learning spaces themselves, to form and join communities and to create, consume, remix, and share material" [4]. PLEs provide more responsibility and more independence for learners. They "imply redrawing the balance between institutional learning and learning in the wider world" [9].
- Personal or mobile devices are perhaps the most rapidly growing category of technology for informal learning environments. The increasing diffusion of portable devices such as tablet PCs, Personal Digital Assistants (PDAs) and mobile phones offer an increasingly valuable potential to support new ways of self-directed, informal and creative learning anytime and anywhere [10].

This raises three essential questions in this context:

1. How can creative cognitive processes foster and enhance science and technology education in general and how can students get the chance to conduct creative experimentation in the mode of learner-driven inquiry in particular?
2. How can students document their respective learning processes on the basis of their self-generated multimedia content and creatively write their laboratory reports and exams on the one hand, and how can teachers guide the student through these processes on the other hand?
3. How can this be fostered by the assistance of personal mobile learning environments on the basis of portable devices and remote labs?

The proposed solution in this chapter is a personal learning environment based on mobile technology that can integrate remote labs and an e-portfolio system to facilitate and nurture creative science and technology learning.

The presented contribution is based on the achievements of the recently completed *PeTEX–Platform for E-Learning and Telemetric Experimentation* project [11]. The aim of PeTEX was to design and establish a prototypical E-learning platform for mechanical engineering education, training [12], [13] and workplace learning [14]. The system development integrated remote labs and socio-technical requirements so as to open new dimensions of knowledge acquisition, particularly where experiments are the core elements of learning [15]. The proposed conceptual framework for secondary STEM education, which could also be implemented in the *OLAREX* context, enhances PeTEX to a mobile learning environment by integrating e-portfolio software. It extends didactical possibilities by adopting a creative learning approach [16]. This work is a subtask of the follow-up project *ELLI–Excellent Teaching and Learning in Engineering Education* [17], which will be funded funded by the German Ministry of Research and Education until 2016.

2. The inquiry laboratory in STEM education

Understanding learning from a constructivist viewpoint requires a focus on the creativity of learning. Learners transform new experiences into personal knowledge by decomposing relevant bits of existing actions and understanding while constructing connections with novel concepts and new ways of resolving tasks. “According to constructivism, a lab inquiry engages students actively in processes of constructing knowledge, integrating it with existing knowledge, and applying knowledge; such processes bring about gradual knowledge revisions and conceptual changes” [18].

Research on the effects of laboratory activities outlines that involving students in authentic inquiry helps them to:

– construct their own understanding of science concepts [19]
– construct knowledge schemes and solve problems [20], [21]
– practice science as scientists [22]
– nurture positive attitudes towards science [23]
– evolve critical thinking and decision-making skills [24], and
– creatively develop their own research questions [25],[26].

“Unfortunately, science laboratory materials and exercises usually provided to teachers of science, K-16, are still centred on traditional methods of the past decades [27]. Ref. [28] compared traditional verification-type laboratory and the inquiry-based laboratories, concluding ‘that in verification-type laboratory instruction, the teacher identifies the problem to be investigated, relates the investigation to previous work, conducts the demonstrations, and gives explicit guidelines that students have to follow’. [29] explained [the disadvantage] that in verification experiments learners quickly realize that they must somehow generate, copy, or paraphrase the knowledge claim that is desired by the teacher and thus laboratory report writing can easily become a rote activity”. In contrast, in an inquiry laboratory the teacher asks students to formulate problems, to relate their investigation to previous work, to state the purpose of the investigation, to identify the problem, to predict possible results, to specify approaches and resolution procedures, and finally to perform the investigation [28].

A. *Remote and virtual labs: interactive tele-operated equipment*

Deploying remote and virtual laboratories provides a vast variety of opportunities to implement creative experimentation into secondary

STEM education following the path of inquiry learning. Many programs now incorporate remote (and/or virtual) labs into their instruction to extend the effectiveness of scarce resources and to share equipment with other institutions and locations [7], [8]. Students can be engaged in:

- blended and online learning scenarios at any time and from anywhere they have Internet access
- learning activities which can take longer than a typical class meeting time
- multi-part assignments which require students to use equipment for several short periods over the span of a week or longer
- socio-technically enhanced opportunities for student collaboration
- building up their own knowledge schemes using the tele-operated equipment provided by the remote labs.

Even risky experiments that may damage the equipment can be conducted in a completely virtual manner.

With the PeTEX project, the entire tele-operated experimental environment was made available by a customized Moodle system featuring an in-house developed Moodle extension. However, the key aspect in order to support the entire process for "active experimentation" is the integration of an appropriate level of interaction and feedback into the tele-operated experimental setup. One example in the context of manufacturing technology, more precisely forming technology, is the use of such a special lab concept for material characterization [30]. The complete experimental setup (Fig. 1) has been transformed to a new level of interaction by using innovative engineering designs, modern automation concepts, measurement technology and robotics, as shown in Fig. 2.

All aspects were connected by developing a clear, usable and interactive real-time feedback user interface of the running experiment. Fig. 3 shows the main screen of the developed graphical user interface for the uniaxial tensile test (for a detailed description see [7], [12] and [30]). With this remote lab set-up, students have the unique chance to tackle practical experimentation methods and are encouraged to develop their own scientific understanding and reasoning on the basis of their own individual and collective curiosity and creativity.

Figure 1

Picture of the tensile testing machine taken by the on-site camera.

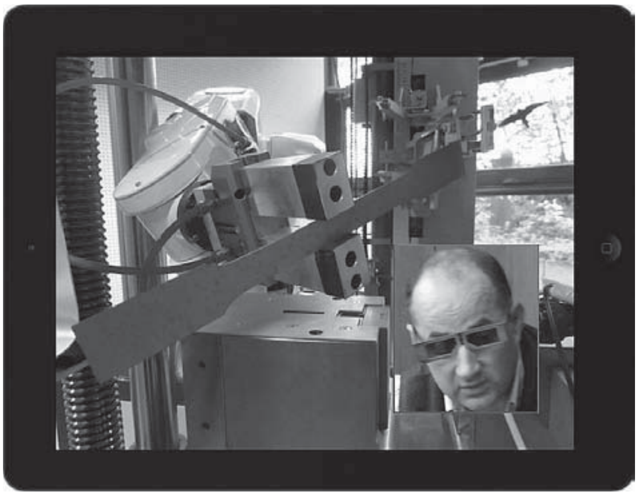

Figure 2

Local site robot positioning a specimen. The small screen is an image from the remote site taken by a tablet PC, showing an expert in the field of online engineering and experimentation concentrating on remotely investigating anomalies on the surface of the specimen with special 3D goggle glasses.

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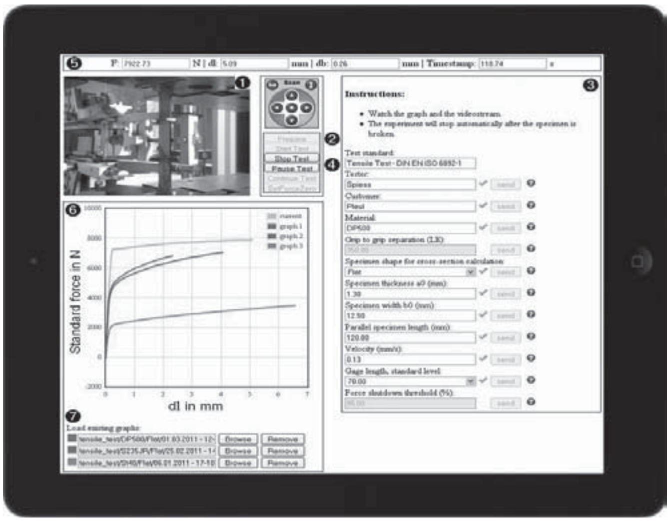

Figure 3

Interface of the tele-operated experiment. Using the live camera stream (1), users can investigate the surrounding test apparatus, e.g. sensors or clamping devices. The experiment is prepared (2) by using the integrated 6-axis robot to select and check an appropriate specimen. Relevant test parameters (3) can be freely set to configure the experiment. After the initialization of the test (4), the robot positions the specimen in the fully automatic clamping device. During the test, a high level of interaction is provided for the user by manipulating the camera view or pausing and continuing the test, causing specific material responses. This phenomenon is plotted in the real time diagram (6) and can also be inferred from the real time test data in the header bar (5). By using the data base (7) and the graph, comparisons with prior test data can be made (6). Once the experiment is over, learners are provided with data packages including all the results for further analysis and investigation.

3. **Mobile personal learning environments and E-portfolios**

Gay in [6] states that an approach driven by a personal and mobile learning environment "…does not only provide personal spaces, which belong to and are controlled by the user, but also requires a social context by offering means to connect with other personal spaces for effective knowledge sharing and collaborative knowledge creation".

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As the name might suggest, E-portfolios, as one application of personal learning environments, are based on the broad conception of portfolios. The conventional portfolio enables learners to collect, pool and organize different kinds of documents within a folder in order to reflect their respective learning processes, as well as to edit and to present them. E-portfolios support the same processes but are based on ICT, are accessible online and provide a collection of different varieties of digital data and multimedia as well as content like texts, tables, photos, videos and audio. E-Portfolio-based PLE software, e.g., Mahara, can conveniently be combined with an LCMS based on Moodle. The integrating application Mahoodle combines the properties and functions of the teacher-led LCMS Moodle and the learner-led e-portfolio Mahara with a PLE which can be deployed as "a facility for an individual [or a group of individuals] to access, aggregate, configure and manipulate digital artefacts of their ongoing learning experiences" [31].

In addition, portable devices whose unique achievements include accessibility, immediacy and users' mobility open up an extensive variety of novel occasions for creative inquiry learning across locations and time. Since students are always on the move and changing in and out of interaction with technology, periods of open time can be utilized for learning and working with e-portfolio software and the related laboratory equipment. This can be initiated virtually anywhere [32], [33].

4. **Creativity and teaching**

[34] states that someone is being creative if they come up with something new and genuine like a novel explanation: "The claim we want to make is that the creativity embodied in coming up with a new explanation is at once the essence of what it means to think, and the heart of what we mean by understanding".

Based on a teacher survey, [35] delivered a definition of creativity in the context of education, as follows:

- When a student comes up with an idea that is new to the student, then the idea is creative.
- Good creative ideas are better than bad creative ideas, but both are creative.

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– Thinking “outside of the box” is adequate even if it comes from “out of the field”.
– At some point, creative ideas should be appropriate to the task at hand or some redefinition of that task.

From the perspective of problem solving, which is essential in science and technology contexts, creativity can be interpreted as interplay between divergent and convergent thinking: while divergent thinking emphasizes on ideation, the uncensored and undistorted production of several responses to a specific task, convergent thinking aims at selecting and evaluating the viable ideas as solutions, the process of arriving at one or more right answers to solve the problem [36].

According to [35], teachers find value in most student ideas and often find great value in things that do not work. A ‘good’ bad idea is often rich in interpretive and ultimately instructional potential. A bad idea is one step further along the creative path than no idea, and good ideas will follow the bad ones. The moments when students’ ideas “… go astray are often the most informative about how students are thinking about the problem or content under consideration. They are windows to the thinking processes of the students” [35]. Moreover, the application of mobile devices can boost creative thinking processes because new ideas mainly come spontaneously. Having the mobile device handy allows the user to at least make a note of an idea or even record it, as well as storing observed artefacts and activities and working on them at a later time [37].

A. *Learning objectives to foster creativity in secondary STEM education*

A model of six facets for fostering creativity in the context of education for analyzing, defining and stimulating new learning objectives and learning activities is given. The model is delivered by [38-41]. These six facets are:

1. Developing self-reflective learning skills: Learners break out of their receptive habits and start to question any information given by the teacher. An internal dialogue takes place and knowledge becomes “constructed” rather than “adopted”.
2. Developing independent learning skills: Teachers stop determining the way students learn. Instead, students start to search for relevant

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literature on their own, for example, to make their own decisions about structuring a text or even to find their own research questions and to choose adequate methods for answering them.

3. Enhancing curiosity and motivation: This aspect is related to all measures that contribute to increased motivation, for instance, linking a theoretical question to a practical example or presenting.
4. Learning by doing: Students learn by creating a kind of “product”. Depending on the discipline, this might be a presentation, an interview, a questionnaire, a machine, a website, a computer program or similar. Students act like “real” researchers.
5. Evolving multi-perspective thinking: Learners overcome thinking within the limits of their respective disciplines or prejudiced thinking. Along with that, they automatically learn to consider an issue from different points of view and to use thinking methods which prevent their brains from being “structurally lazy” [42].
6. Reaching for original ideas: Learners aim to obtain new, original ideas and prepare themselves to be as ready-to-receive as possible. Although acquiring original ideas cannot be forced, the reception of original ideas can be fostered by applying appropriate creative techniques and by creating a suitable environment (allowing students to make mistakes and to express unconventional ideas without being laughed at or rejected).

5. Creative learning with E-Portfolios and tele-operated experiments

A commonly expressed challenge in association with open learning concepts is that a teacher is in need of a sophisticated concept in order to document and evaluate the learners’ behavior as well as achievements throughout the learning processes taking place in the laboratory. Obviously, such a concept requires different approaches for the instructor to accompany the learner along the learning process and, above all, to evaluate the achieved learning outcomes. As mentioned above, the e-portfolio is a frequently discussed software solution for open learning contexts [43] which has been methodologically well established by its predecessor without the leading vowel: “e-portfolios are hardly a new idea in the fast developing field of Technology Enhanced Learning” [44].

By creating and designing personal portfolios like a multimedia field diary, learners can document their own learning and research processes [45], [46]. They get the chance to:

- arrange all data and information they would like to collect or share with others in different orders
- present experiments and their results or show photos from the test set-up
- write notes and reflections on their experiments during their research-based learning processes
- explain their research results and thoughts to themselves and others
- collect ideas in creative moments, and to organize and improve them whenever needed
- support collaboration by allowing other learners and teachers to have access to their e-portfolios
- prepare, write and revise the lab report as a living document based on their learner-generated multimedia content.

This reflection on learning processes and outcomes is an important aspect required/needed to foster the students' personal creative learning cycles [47]. Especially for learners, the e-portfolio as a personal learning documentation and field diary can always provide orientation and a checkpoint in topics of their own inquiry [48], [49].

In the same way, teachers have the option to evaluate the actions of learners by observing/considering and reviewing their students' e-portfolios. Since other selectable persons or groups are able to view the collection in the portfolio, it can be stated that the e-portfolio is not only a versatile instrument for both individual learning documentation and learning-related reflection processes, but also an especially valuable tool for collaborative communication.

In the following chapters, different task-based scaffolding scenarios will be presented in order to explain how personal learning environments featuring the combination of remote labs, e-portfolios and mobile devices can enrich secondary STEM education and formal classroom activities. These scenarios differ mainly in terms of teacher-led or self-directed individual and collaborative learning processes. The scenarios are based and premised on the model of the six facets for faceting creativity, as presented above.

A. *Facet 1 - Developing self-reflective learning skills: Evolving critical thinking by harnessing technological pitfalls*

One severe and often misleading disadvantage for users of remote labs or simulations is the option to conduct experiments which might be harmful or impossible to perform under real circumstances. In order to raise critical awareness of this technological pitfall, a misleading environment can be harnessed to make students familiar with a critical approach to information as well as invalid use of ICT tools. In order to achieve this goal, teachers can assign tasks to their students which are impossible to solve, or can provide false information that leads to seemingly correct but erroneous results of the experiments. In both cases, the students will be irritated while performing the experiment and they will be challenged to find the cause.

A common teaching topic in secondary STEM education is the area of digital process control. In order to foster self-reflective learning, teachers could ask their students to develop a set of traffic lights for a strongly frequented road intersection. The simulation system MSM PLC3D offers an interface for the connection of a programming language and a simulation so it can be used for simulating the traffic lights. In order to enable a critical attitude towards given information, teachers can provide students with a faulty programming code so that all cars might have a green light simultaneously (or, to spice it up, cars and pedestrians have green lights at the same time). Simulated accidents would be the result and students would have to verify the given information as well as identify the mistake and reprogram the system. The achieved learning outcome would be (besides the computer control topic) that students mistrust and reflect on given information rather than simply receiving it, as they can experience the consequences of applying misleading information without putting it into question.

B. *Facet 2 - Developing independent learning skills: Improving self-reliance and self-confidence towards technical issues*

Remote experiments combined with PLEs make it possible to let students learn more independently. They enable them to search for information, to plan and to conduct experiments as well as make decisions on their own, facilitating the 'flip from teaching to learning'. Photovoltaics are another typical secondary STEM topic used in order to illustrate the feasibility of conducting task-based learning scenarios featuring the combination of remote labs, e-portfolios and mobile devices. Instead of simply giving the students information about solar power, teachers could ask them a relatively open question, for instance: "What is needed to charge an iPhone by solar power?" The information needed to accomplish this task is available on the Internet; furthermore, students can access remote labs for solar electricity (e.g. TU Berlin University has established a remote lab for solar cells [50]) and perform related experiments on the influence of different light sources on power output in order to provide adequate answers for the iPhone-question. Admittedly, the open question represents a quite challenging and possibly confounding and time-consuming scenario, especially in the early stages of the problem solving process and hence is not suitable for inexperienced learners. In order to give assistance, teachers have to carefully monitor their students' learning progress. If they notice difficulties or confusion among their students, teachers will have to help them "to help themselves" without providing completed solutions. For this purpose, PLEs are valuable tools that enable teachers to monitor their students' learning steps and provide feedback to them, while students on the system's other end can ask for help at anytime. As a reward for using a learning scenario, students not only incorporate a wide range of aspects about solar electricity but will also learn to plan a small research project, as well as putting it into practice and feeling responsible for it and their respective learning success. In the long run, performing small learning tasks on their own will improve their self-reliance and self-confidence towards technical issues.

C. *Facet 3 - Tackling curiosity and motivation by intertwining technical issues with students' environmental experiences*

Generally speaking, learning with experiments (remote or not) and real-world questions are a suitable combination to support students' motivation to learn, compared to sitting in a classroom and being restricted to receiving information presented by a teacher without active multi-directional participation. Remote labs have several advantages regarding students' creativity: they are readily available throughout the day, so students can carry out experiments whenever they have a good idea and therefore do not have to wait for the next STEM lesson to test their respective ideas. Besides, they do not have to bother to ask the teacher for permission to perform an experiment. They can conduct it whenever they wish and, if they own a mobile device, wherever they are.

Nevertheless, the question of rendering subject matter more interesting for students in order to tackle their curiosity and motivation is always worth asking. A well-known approach towards increasing students' motivation is to utilize practical questions and tasks. Therefore, combining practical issues taken directly from the students' daily environment as well as remote experiments or simulations might be the silver bullet of situated experimental learning. For example, one thing which almost any student has done in her or his life without using higher science is that of making a paper plane. A possible task in secondary STEM education would be to develop the most effective paper plane as part of a small competition or –in technical terms– to experience the correlation between drag and shape. Students could be asked to use a wind tunnel simulation in order to test different wing shapes while creating their paper plane. By doing so, they should parenthetically be enabled to determine the drag coefficient and could use the simulation to try several varieties of their paper plane, in order to increase its range by reducing its drag. Finally, they could build the real paper plane based on their wind tunnel experiments and hold the competition by measuring the respective range of each plane under similar conditions. All flight tests can be recorded with the camera inside the mobile device and be analyzed at a later time. The inventors of the most effective paper plane (is it really the one with the lowest c_d value?) would receive a small prize. This is just one example of how to combine technical issues with students' environmental experiences.

D. *Facet 4 - Learning by doing: Designing and building functional models*

Once again, the use of (remote) experiments and simulations can basically foster students' creativity through their emphasis on learning by accomplishing a task. Since experimental learning as a means of scaffolding always features some sort of product to be created, this learning method appears suitable in order to achieve this goal as it might also strengthen the students' awareness of their creative potential. Besides, exposing the learning outcome to a larger interest and external assessments are valuable factors in tackling students' intrinsic motivation. For this purpose, the PLEs can be used to render the readily documented learning process accessible for externals.

Designing and building fully functional models of wind turbines is another regular STEM education issue. In order to accomplish this task, students need some knowledge of suitable materials for this purpose. Wind turbines –especially under off-shore conditions– are exposed to severe weather conditions and yet have to endure them as proof of their reliability. A conceivable learning assignment for students in this area could feature the use of remote experiments with an emphasis on material properties. Students could be asked to develop and present a model of a wind turbine which simultaneously incorporates the particularly contradictive attributes of resilience as well as energy and economic effectiveness (altogether with the performed experiments) in their PLE. In order to make it a "real" product and to release the didactic scaffolding, authentic engineers from a wind turbine company could be asked to have a look at the PLEs and to provide brief feedback. To conclude the project, it would be a great idea –in order to raise intrinsic motivation– to visit the wind turbine company together with students and to have them talking with engineers who deal with the same issues. Of course, wind turbines are just one example. The teacher's key challenge for this scenario is to find a company whose representatives could function as external role models in order to focus students on the final outcome and to strengthen the product idea in STEM education.

To summarize, this task-based scenario resembles a case study but enriches it with authentic professional role models (the cooperating engineers) as well as the remote or simulated material sciences laboratory as a means of learning enhancement for relevant subject matter.

E. *Facet 5 - Evolving multi-perspective thinking: Overcoming cognitive barriers*

This scenario can foster students' ability to think about their questions from different perspectives: imagining a student who had performed an experiment assigned to him by the teacher, he/ she contingently does not know why the experiment did not show the expected results or does not know how to interpret them correctly. He asks himself why the experiment did not work according to plan but cannot find a satisfactory answer. While writing his e-portfolio as documentation for the teacher's evaluation, he could start the "creative-help app.", a *de facto* wizard application within the PeTEX LCMS intended to help him develop different perspectives on the same problem:

– The student is asked to do a (mental) headstand following the question: "What else could I do to get the wrong results from experimenting?"
– If this should not suffice, he will be asked to describe his experiential design and assumptions in a way that a ten-year-old could understand it.
– If those methods, which are fairly close to the problem, still cannot help him, the "creative-help app." will suggest a force-fit technique by showing a picture that does not have anything in common with a problem (for example, a lady beetle or a daisy chain for younger pupils, a choice selection of wine bottles for an older student who wishes to feel like experienced scholars do) and asking the student to find relationships between the picture and his experiment.

This set of methods can help students to leave the well-trodden paths and forces them to look at their problem from completely different perspectives. This often results in unconventional or provocative ideas, but rethinking the obviously unsuitable solutions sometimes leads to the one really good idea, which would not have appeared without making the detour.

F. *Facet 6 - Reaching for original ideas: Breaking rules and posing one's own questions*

The permission for "breaking all rules and posing one's own questions" is the supreme discipline in creativity education. There are several options available to make for learner-led inquiry, investigation, discovery and reasoning. One fictional but already possible case in the creative STEM classroom of the future, inspired by reading the chapter "Earth" in [51], is presented as follows:

Imagine that the student “Marty McFly” [30], who had gathered a lot of experience in learning with remote labs over time, had almost completely finished his course and had enrolled in the final stage of his STEM program: the “Breaking all Rules and Posing one’s Own Questions” course. To formulate his own research question, McFly had evaluated his e-portfolio, including all materials, comments, notes, unanswered questions and interesting ideas he had collected and assembled over time. Now, what should he do with it? What valuable inquiry could he condense from all that data? He started incubating.

While McFly was watching a video in his e-portfolio of the oxyhydrogen test from the last chemistry class and manipulating the sound of the bang over and over again with the mixer console of his laptop, he suddenly got an idea: Marty McFly had been interested in ‘sustainable engineering’ and ‘circular economy’ for quite a long time and he was still very impressed by a TV documentary he had downloaded into his e-portfolio on uncontrolled natural biomass/gas emission and their negative effects on global warming. Biomass and biogas as unimpeded by-products of cattle farming would become more and more critical for the chemical composition of the atmosphere and also proved capable of accelerating the greenhouse effect. In order to reduce the production and consumption of meat (“eating less steaks and burgers”) by causing a reduction in unimpeded methane emission, a change in the attitude and eating habits of young consumers would be indispensable to take the tiller, considered Marty. This debate could be initiated and reinforced among the “youngsters” in school by means of experiential laboratory learning to understand the basic underlying chemical processes of methane production and emission. These learning processes could generate more awareness of and insight into the negative environmental consequences that increasing meat consumption in the western world would yield.

McFly decided to contact two university professors, Gus McHardy and Jeff McLaurel, since they gave lessons in the “Breaking all Rules and Posing one’s Own Questions” course at Marty’s school from time to time. They worked in the field of advanced online engineering and experimentation. McHardy and McLaurel preferred a radically student-centred approach and were already convinced that the creativity of youngsters may still not be too “polluted” with “formal science education and restricting administration”. Their basic assumption for transformative higher order learning was that the best way to deeply understand the epistemological core of experimentation is to not only carry out experiments but to actively design them. To this end, they challenged the creative attitude of their students by letting them develop some form of creative concepts for remote labs, regardless of what they might come up with. While creatively discovering and solving all the who, for whom, how, what, when, where, and why-problems that would emerge during such a design process, students would definitely learn and generate the most valuable competences needed to understand science and technology in a higher-order mode. As a special reward, the best proposal of each year would be put into practice as a remote experiment at Deusto Weblab in Bilbao, Spain and prospectively be distributed online to STEM courses at schools, science museums and universities all over Europe. Motivated by this chance of success, McFly elaborated the idea of a sophisticated remote lab for conveniently analyzing the unimpeded by-products of cattle farming to question its effects on the chemical composition of the atmosphere. To this end, students from all over Europe would collect cow droppings or even cow flatulence probes during class outings or special biology class field trips, simply send the probes to Weblab-Deusto and later on analyze their respective compositions, as well as methane percentages within a kind of remotely accessible fully automated experimentation cabin. Being quite convinced that this lab could really change the meat eating habits and attitudes of future mankind if all school kids were educated with it, McFly booked an online consultation with Prof. McHardy and Prof. McLaurel to present his idea of a "Cow Emission Learning Lab (CELL)" for Weblab-Deusto.

While Prof. McHardy was proudly emphasizing that Prof. McLaurel could transform nearly every idea for an experiment into a real remote lab, McLaurel looked only cautiously optimistic (see Fig. 4). His first appraisal was that this "valuable approach" would be "far beyond the financial framework" and would need "the permission of his head of department or even the rector of his university". Finally, the paper work involved in receiving such an approval would be time-consuming and bristled with a lot of unexpected difficulties and obstacles. He had experienced that once and had decided to never face it again. But he recommended McFly to search for books in the library with topics like "ingeniously failed", or "fates of great explorers and inventors". Reading this would explain a lot.

Figure 4

Marty McFly (small window on the tablet device) presented a video of a biogas inflaming experiment done in his little home laboratory to the two professors McHardy and McLaurel (from left to right on Marty's mobile phone screen). While Prof. McHardy (l.) emphazised that Prof. McLaurel (r.) could transform nearly every idea for an experiment into a real remote lab, McLaurel looked only cautiously optimistic. He stressed that this "very creative approach" for a Europe-wide analysis of unimpeded byproducts of cattle farming in a cow emission learning lab would certainly need a lot of cost-extensive novel lab equipment, logistics and secure storage capacity for all the probes. Plus, insufficient odor protection or uncontrolled ignition of leaking gases could cause major inconveniences for those who have to stay on site. Marty showed an annoyed facial expression, but this was not caused by the rejection of his idea but from a faulty operation: instead of starting another video of the biogas inflaming experiment to persuade McLaurel, he tapped the wrong icon on his touch screen and the pad camera immediately took a picture of him while staring directly into the flashlight. Moreover, since he was never interested in all the privacy settings, the pad automatically uploaded the picture to the digital public space of his course, amusing his classmates rather a lot.

McFly, always optimistic, did not interpret this answer as a complete rejection of his idea but as valuable feedback for improving his concept according to the depicted hurdles and constraints. Writing down all his ideas, reflections, notes, comments after the conversation into his portfolio, he suddenly came to the conclusion that being creative by *really* “Breaking all Rules and Posing one’s Own Questions” may also create a lot of *real* resistance from teachers, superiors, institutions and others who still need to be involved and convinced to transform an idea into innovation. He started incubating again on his lab… “What about the production and consumption of cow’s milk e.g. in comparison to soya milk?”

6. **Conclusion**

In this chapter we explained how the integration of remote labs and e-portfolios into mobile personal learning environments can offer novel opportunities to foster students’ creative learning in STEM education. Generally speaking, personal learning environments and remote experiments are adequate opportunities to perform, document and share experiments whenever students wish to do so and, if using mobile devices, wherever they please. Moreover, allowing students to learn in this way already incorporates fostering their creativity with respect to the six facets of creativity in education. Each (remote) experiment is some sort of a product (facet 4, learning by doing), is supposed to increase students’ curiosity and motivation (facet 3, compared to just sitting in a classroom and listening to the teacher) and fosters their self-reliance (facet 2, by doing something on their own). However, we have shown that there are still a few ways to promote creativity even better with carefully designed task-based learning scenarios which focus on students’ self-reflective learning, their life world, practical issues, external (“real world”) reviewers, their independence and even self-responsibility for the learning process, as well as their ability to use multi-perspective thinking. Some examples were given to show how easily these goals can be achieved by means of remote experiments or simulations, combined with mobile devices and a personal learning environment as well as scaffolding scenarios. This is one essential way for students to reach high level learning outcomes and thereby develop the basis of fundamental competences for their future personal, school, academic or professional life, as well as tackling attitudes like curiosity, creative self-efficacy, agency and responsibility. If students are allowed to evolve their own research questions, choose suitable experimentation designs and finally

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perform the experiment, they will be able to develop a kind of "spirit of inquiry and research" [52]. This spirit is one important premise for developing original ideas.

Ultimately, the example for facet 6 (reaching for original ideas) is not as fictional as it seems. A Web inquiry in a multi-perspective mode (facet 5) during a STEM class on topics like "cow emission" and "cow emission labs for kids" would present a lot of apparently uncommon examples of what is already going on in informal environmental STEM education. Only the presented synthesis within a remote lab cannot be carried out as yet.

"*The creative attitude is the desire to go against the mainstream. But such desires are stopped by parents, in school, at work–nearly everywhere. The creative attitude entails posing one's own questions, not answering the questions of others, and it is not always easy to get away with such a point of view*" [1].

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