

The Role of Non-Formal Contexts in Teacher Education for STEM:

The Case of horno³ Science and Technology Interactive Centre

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Abstract

Teacher education can benefit directly from experiences in non-formal settings. This article presents a research study with elementary teachers who were teaching in public schools in the state of Nuevo León, México, and participated in a STEM Continuous Professional Development (CPD) workshop. The workshop provided a platform for teachers to interact with scientists and disseminators of science, allowing the appropriation of scientific knowledge applied to everyday activities and settings. Participants improved the quality of their teaching practices in classrooms and gained a new understanding of STEM subjects, enabling them to promote inspiring learning experiences with their students, where dialogue, experimentation and elucidation became an important part of their lessons. The study was carried out using ethnographic tools for analysing recorded videos, 15 sets of field notes, and 49 questionnaires. The sequential analysis of talk and gestures in their participation in the CPD workshop demonstrated high levels of involvement, creativity, and collaborative solution of STEM problems.

Keywords: Non-Formal Education, Teacher Education, STEM Education

Background and Context

Educational research focusing on teachers' ideas about science in Mexico in the last ten years has been widely documented for teachers in service. Gómez Galindo et al. (2013) reviewed the state of knowledge in this field in Mexico from 2002 to 2011 and identified more than 20 articles on this topic. For instance, Guerra-Ramos et al. (2005) point out that teachers seem to be able to accommodate their pedagogical ideas into different educational contexts; however, in some cases they also seem to struggle to clarify stereotypical ideas about professional scientific practices. Likewise, the work of García Ruiz et al. (2006, 2008) focuses on the study of attitudes toward science, finding that these are mostly negative and distant from teachers' interests. Regarding disciplinary knowledge, most of the publications refer to teachers at secondary level. Studies carried out by Flores Camacho (2007), García Franco et al. (2006) and Gallegos et al. (2005) found that teachers who participated in Continuous Professional Development (CPD) courses on science do not have sufficient basic knowledge to teach scientific disciplines at secondary level. They also noted that teachers' ideas are similar to those of their students, and share conceptual errors (Calixto Flores 2004). An important conclusion of several of these studies is that the ideas teachers have about science are not directly related to their practice; teachers who took institutional CPD courses on science education and changed some of their ideas about science, did not change their practice in classrooms.

Thus, for teachers in service the possibility of reducing the gap between new curricular proposals, their conceptual misunderstandings, and their performance in school, are related to their opportunity to participate in CPD programmes with the capacity of providing them with tools for personal development, enriching their social conditions and empowering them to overcome the traditionally established educational

practices. This is also true in the particular case of science education, where the CPD programmes expect to educate teachers with a contemporary vision and experiences associated with how scientific knowledge is constructed, alongside the ability to design socio-constructivist scenarios for their students' learning progress (Barahona et al. 2014). In addition, these programmes have to consider not only the conceptual challenges for teachers but also their emotional and attitudinal facets. Some studies have shown teachers experiment against a background of feelings of insecurity and vulnerability in their daily work (Sutton and Wheatley 2003), and in teaching science, there is some reluctance to fulfil practical work due to the lack of confidence and sense of being out of control (Guerra-Ramos et al. 2011).

The Role of STEM in Teacher Training

The evidence presented in the previous section demonstrates how traditional scientific teacher education no longer meets the needs of teachers to design and implement innovative educational strategies. We consider that a STEM perspective could be an alternative for traditional scientific education. STEM programmes are characterised by the design of problems where Science, Technology, Engineering and Mathematics must be linked and used in a productive way to find solutions to problems. Due to the diversity of possible problems to be addressed using a STEM perspective, students are exposed to a variety of scientific and engineering activities. The activities may include participation in festivals addressing contemporary issues on energy and sustainability, as well as competitions on robotics, solving rescue challenges, designing solutions for industry and commerce, and even designing the capacity of robots to play football or perform a

choreography, to name but a few. Hence, learning is both experiential and situated in the context of solving problems relevant for students and society. This is a productive approach in which we can prepare the next generation of STEM professionals: scientists, engineers, architects and technology professionals to ensure the competitiveness of our society (Sakar 2016). Also, the STEM perspective brings positive experiences for teachers, affording group work and problem solving of situated problems in science.

However, teachers need to be educated to fulfil the demands of these activities, many of them taking place in non-formal scenarios such as museums and after-school clubs. For instance, some of these demands can be expressed in the form of the following questions: How can students be guided to construct new scientific understandings derived from a STEM experience in which they were involved? How can we help teachers to feel comfortable and competent in these situations? In this article, we will present a case study of teacher involvement in museum activities that will offer some responses to these issues.

STEM Culture and Hands-On Activities: The Case of horn³ Science Museum

Experiential and situated learning are aspects of education where science museums and centres can take a leading role (Falk and Dierking 2013, 2000). Museum horn³ is an interactive centre dedicated to scientific education using the building and historical context of what was a blast furnace for producing steel in the city of Monterrey, Mexico. Most of the activities at horn³ are STEM focused activities. Learners can do field trips and practise Science during 1-day sessions. Activities for children include long courses (10 weekly sessions, 35 hours) in order to develop their interest in pursuing STEM careers. These children's courses have been a tradition since 2007, and follow-up studies

indicate that 78% of the participants, who are now more than 18 years old, are studying STEM careers. Nearly 50% of the participants belong to low income families, most of them considered at risk because of violence and poverty, and where school dropout is common (Fernández-Limón 2014). These courses have been taught in different places, including *horno*³, but also in community centres and private schools. *horno*³ has developed a partnership with different funders in order to cover the costs of these activities in community centres. Thus, socially responsible companies, the federal government, and the state government of Nuevo León, have sponsored school children, paying for registration fees and transportation to different venues, in public institutions. *horno*³ has also other outreach activities such as “Science in the City”, which is a free programme where families participate in STEM activities. These activities take place in shopping centres, parks, and other public places. In this respect, the provision of non-formal courses and activities by *horno*³ seeks to develop participants’ problem-solving skills, as close as possible to those used by experts on STEM subjects.

Finally, since 2009, *horno*³ has implemented a workshop in scientific competencies for teachers. In this workshop, a STEM perspective is implemented transversally to develop scientific conceptual relations, as well as their connection to the world and to contextualised problem solving relevant to communities in the metropolitan area of Monterrey. The proposal of this CPD experience is to contribute to the education of teachers using the affordances of non-formal settings and activities that teachers usually do not have access to in formal CPD programmes. Key practices such as planning before performance, collaborative reviewing processes (Simmons and Lunetta 1993), and the use of contextualised frames of reference towards sustainable social practices (Colucci-Gray et al. 2006), are part of the model used for designing the CPD courses offered for teachers. This model also affords the generation of an award scheme

supporting teacher empowerment, and represents an opportunity to explore the legitimacy of museums as productive settings for the development of STEM activities for teacher education. Notably, science museums can provide a framework for involving teachers in environments where teachers themselves are engaged in their own learning tasks.

This study examines the perspective of STEM education situated in non-formal settings, such as the museum horn³, analysing how activities can be seen as an opportunity for dialogic participation and a source of knowledge and confidence for teachers involved in these experiences.

Dialogue and Transformative Education for STEM Activities

Increasingly, transformative learning and dialogue are influencing the development of a pedagogy for teaching STEM subjects (Fernández-Cárdenas 2014; Wegerif 2017; Kazak, Wegerif, and Fujita 2015; Clifford and Montgomery 2015; Gutierrez and Vossoughi 2010; Bell 2016), and the role of museums and other non-formal settings for educating teachers on STEM subjects has been increasingly recognised. In 1991, the *International Journal of Science Education* published a special issue edited by Lucas on informal sources for learning in science. Also, in 1997 *Science Education* published a special issue on informal science education, co-edited by Dierking and Martin. Lastly, in 2003 Feher and Rennie presented an issue on research in science learning in informal environments in the *Journal of Research in Science Teaching*. In these issues, almost all the papers inquire about the interactions of visitors and exhibitions, focusing on the use of language, learning outcomes and the characteristics of exhibitions. Both Lucas (1991) and Dierking and Martin (1997) pointed out that to reduce the gap between museums and educational

research in non-formal settings we needed to broaden the scope in methodological and content domains. In this respect, Feher and Rennie (2003) suggested that one area that has been neglected is the participation of teachers in museums and the various ways in which they can learn in these settings. The role of museums involving teachers so that they value and get enthused about science and technology has not been sufficiently considered.

Although teacher learning in museums has not been sufficiently investigated, this paper aims to help in constructing the research agenda in the area considering the points Rennie and colleagues describe in their work (Rennie, Feher, Dierking and Falk 2003). Following Schauble et al. (1997), these authors define three organising themes: (a) learning and learning environments; (b) interpretation, meaning, and explanation; and (c) identity, motivation, and interest. The relation between motivation, museums, and STEM education can derive from the possibility of teachers for attending museums voluntarily, so that their expectations can differ from the alignment with official policies. At the same time, teachers can consider the possibility of using museums as a place to “play” and have childlike and uninhibited behaviour. The relation between museums, learning, and positive emotional experiences in visitors’ responses are well documented (Bell et al. 2009).

Moreover, science museums need to ensure they help wider audiences to get access to the most relevant and updated debates in scientific and technology issues, through participation in exhibits and other non-formal learning activities. Social interaction and communication with peers and experts is crucial for getting access to these debates which usually involve complex issues and problems (Dierking and Falk 1994; Rennie et al. 2003). These interactions help visitors to engage creatively in conversations while manipulating physical and digital artefacts (Salinas, Quintero and Fernández–

Cárdenas 2016). The importance of the analysis of successful cases of learning trajectories in museums is related to the recent demand to establish relationships between formal and non-formal educational settings, and for identifying how people can learn in each environment, the relations of people's everyday knowledge and STEM implications, thus generating successful collaborations and providing an effective science education for all (Stocklmayer, Rennie and Gilbert 2010).

The incorporation of STEM activities in CPD courses for teachers is not an easy task. Teachers are not used to integrated lessons or to incorporating the engineering thinking process involved in STEM as part of their teaching, because they are usually trained in specific mathematics or science strategies. Engineering training guides participants to follow a process of thinking and the creation of models, whereas in science education, teachers are trained to use classic experimentation as the main pedagogic model. Instead of engineering and scientific training, we need a focus on STEM education addressing simultaneously the development of academic skills applied to the solution of problems with creativity and innovation, as well as promoting the levelling of differences of access to the use of scientific tools of participants from disadvantaged contexts. Thus, we need to help teachers to appropriate the knowledge and skills to achieve these goals, and we believe that one way to get to this point is by promoting dialogic and transformative approaches in educational practices. This is relevant as teachers can learn to support reflections on power relations, which then can be used to make visible the differences between experts and novices, and finding ways to promote dialogic interactions in order to help newcomers to get the required access and knowledge in control of old-timers in a given field of scientific expertise (Lave and Wenger 1991; Wenger 2010). Therefore, participants can be involved in learning trajectories where they

can use their shared knowledge of STEM subjects to solve problems in their communities and, in parallel, to meet their social needs.

This is even more crucial, given that formal settings have decreased their influence on the achievement of societal goals in education, due to the lack of capacity for promoting creativity, divergent thinking, and collaboration (Robinson 2010). It has been argued that schooling systems need to transform their industrial mind-set into a more post-industrial millennial era way of working, based on collaboration and innovative ways to construct new institutions capable of facing new urgent problems, such as climate change, economic sustainable development, migration, and the construction of societies which are increasingly plural in terms of their culture and interaction of different lifestyles in cities and suburban areas, thus promoting more action-oriented participatory pedagogies (Dillon 2016). As a result, non-formal settings have become increasingly valued as educational spaces where exploration, creativity, and freedom can relate to the development of skills for ensuring that real needs of communities are taken seriously, so that solutions are jointly constructed. Dewey (1909) has been a solid advocate of the promotion of educational systems where curriculum is directly connected to reality on an everyday basis. In line with this, museums and community centres working on STEM activities have legitimated their mission as valid non-formal settings where academic knowledge becomes socially relevant for social change (see also Bhabha 1994; DiGiacomo and Gutiérrez 2016; Rogoff et al. 2016; Gutiérrez 2008).

Methodology

In this study we use ethnographic tools (Castanheira et al. 2001; Gee and Green 1998; Skukauskaitė, Liu, and Green 2007) in order to study the perspective of participants in their own activities and settings. In educational studies, the aim of using ethnographic tools is to describe the way teachers, students and other types of educational agents are involved in settings such as schools and museums. In a related manner, the analysis of talk in participation in situated activities has been used to understand how participants construct meaning as part of the unfolding sequences of turns taking place in collaborative activities (Goodwin 2017; 2007a; 2007b). We are using these analyses along with the results of surveys and field notes to triangulate information in order to produce an informed account of the perspective of participants in a CPD course on STEM subjects. In this paper, we are focusing particularly on one session (number 15 in a series of workshops), which is about the construction of hypotheses when using an inclined plane with different materials, angles and types of toy cars. In particular, we look at learning trajectories of teachers in service working in small groups. Teachers in service make predictions about the distance which will be travelled by a toy car when left freely to run from the top of an inclined plane. The aspects they propose looking at include the angle of the plane, the materials of the car, and the initial velocity of the car. One purpose is to establish causal relationships between the aspects involved in the physical phenomena observed in each experiment, and assess to what extent some aspects depend on each other and can be controlled to perform some desired effect and the relation with engineering design.

Participants

This CPD workshop for teachers was offered for the first time at horn³ in 2009, and was designed by horn³ and Cinvestav Unidad Monterrey. All the participants have been teachers in service in preschool, primary and secondary levels from public schools.

The presentation of the workshop started on September 18th and 19th, 2015, and the last sessions took place on December 15th and 16th, 2015. The data presented in this article were collected from session 15, involving 49 participants: 14 were preschool teachers, 17 primary school teachers, and 18 secondary school teachers.

Instruments and Procedure

The workshop consisted of 15 three-hour sessions. These sessions were divided in 5 modules:

- Life science
- Matter and energy
- Sustainability
- The teacher as a role model
- New technologies and engineering in the classroom

Session 15, located in the last module, addressed the solution of a problem involving an inclined plane and a toy car. We focused on this session as one example of how participants engaged with high levels of involvement and creativity for the collaborative solution of STEM problems. During this session, the class was arranged to work in small groups of four teachers in each table. Groups seated where they wanted, so

they selected their team freely. The material to be used was in the front of the room. The facilitator asked one person of each group to pick up the material in front of the room. When they got back to their teams again, the facilitator gave them the first part of the challenge. They had to build a ramp, so that a car and a truck were able to slide on it. After building the ramp, they had to predict the spot where they think the vehicles would stop. They had to mark the selected spot with a sticker.

The teachers started immediately to build the ramp. The facilitator asked them to first think about the place in the room where they wanted to work, because they were going to try their models. They started playing with the cars simulating ramps without actually building the ramp. The facilitator told them that they could not use the cars and trucks before making their prediction. Only after proposing their hypotheses they were allowed to build the ramp. Some teams added books, notebooks, and chairs to try to elevate the ramps. The conversation focused on height, gravity, the material of the cars and trucks, and the differences in weight for the vehicles. Some teams talked about acceleration, the angle of the ramp related to the distance the car and truck were going to travel. Some teams worked on the tables, some others decided to work on the floor.

When they finished building the ramp, the facilitator told them to put one sticker where they thought the car would stop, and another sticker where they thought the truck would stop. After that, they cut two pieces of different colour yarn covering the same distance predicted for each vehicle and stuck them with masking tape on a given wall. Each team was assigned with a space on a specific wall in the room. In another sticker they had to write: “This is our prediction for our car”, and “This is our prediction for our truck”. After making their predictions and sticking the yarn on the walls, they had to try the car and the truck and make the measure of the actual distance travelled with a yarn of another colour and stick the yarn next to the other lines with the predictions. The teams

talked about weight, distance, gravity, friction, design of the cars and trucks, and stability. All the members of the group were actively participating in the activity.

Results

Analysis of Data

An ethnographic case was constructed detailing the trajectory of participants, describing particularly session 15 of the CPD workshop. The case included the following analytical elements:

- a) Categorisation of topics presented by teachers participating in the workshop, using a semantic lexical analysis (Hatch and Brown 1995; Reyes Angona and Fernández-Cárdenas 2015; Reyes Angona, Fernández-Cárdenas, and Martínez Martínez 2013) of the questionnaires administered at the end of the session.
- b) Analysis of talk in interaction (Goodwin and Heritage 1990; Goodwin 2007; Goodwin 2017) of a transcript of a video with the activities of a small group.
- c) Triangulation of data sources, including detailed ethnographic notes of the session, to increase validity and ensuring we captured the perspective of participants.

Analysis of Questionnaires

The answers of the surveyed participants indicate different types of learning. Beyond the appropriation of disciplinary knowledge, the answers revealed the importance that

participants attributed to the pedagogical model of the course, and the approach focusing on solving problems using a STEM approach. The way of referring to the session allows the identification of three main aspects recognized by participants as relevant in the way they teach STEM subjects:

a) *Learning with enjoyment*: One of the most challenging obstacles for teachers is the election of a pedagogical model for their practice. They usually struggle to find an efficient pedagogy to disseminate scientific findings and its applications to a wider audience, mostly pupils, and in some cases, parents and policy makers. One of the main challenges of such a pedagogy is the goal of learning with enjoyment, especially in STEM subjects, which in many cases are considered boring and difficult to grasp. The challenge is to develop a pedagogy not only limited to the transmission of useful scientific information, but mainly to draw on a pedagogy aimed to co-construct solutions to STEM problems, while providing enjoyment to the learners. The participants of this CPD course seemed to connect with the same sensations of enjoyment as the goals of the pedagogy required in their own classrooms, in relation to the way in which the course was delivered. Below there are some testimonials:

[Table 1 near here]

Participants did not indicate that they got distracted from learning objectives nor did they consider that there was any simplification of the value of STEM subjects, despite the enjoyment and entertainment they had as part of the experience.

b) *Learning by doing*: A semantic analysis of the answers of the survey reveals the lexical density regarding the meaning of “activity”. The following table of the lexical frequencies in the answers regarding their evaluation of the session shows the prevalence of meanings related to the active and practical knowledge, as well as the application of knowledge. In this analysis, the participants’ perspective of the course highlights the importance of learning “by doing”, not only by listening or reading information from a book or transmitted by the instructor (transmitted pedagogical knowledge). Table 2 shows the frequency of the term related to each field, retrieved from the answers of the questionnaires.

[Table 2 near here]

To this lexical mapping, we must include the recurrent emergence of phrases that semantically strengthen the feeling of active learning. Some examples are included in Table 3.

[Table 3 near here]

c) *Problem-solving pedagogy*: Participants insisted on the value of the STEM approach for solving problems in their daily environment as being at the centre of the teaching process. Some participants highlighted the relationship between the contents of the session and common topics of interest, both for them and for their students. One of the participants indicated that the session included “real and interesting topics”. Other statements stand out for the value attributed to the

learners, and their participation in the learning experience. Here we present three examples (Table 4).

[Table 4 near here]

To sum up, the assessment of the surveyed participants of the session was favourable, especially because they found a positive emotional experience, reasonably interesting, notably active, and most of all, different from what they already had experienced. It is worth mentioning some statements from which this conclusion was obtained: “Activities that can be applied in an innovative way”, “A different way to approach interesting topics”, “It provides alternatives to raise interest in studying”, “Systematised and planned, but still innovative”. The implication of this analysis for teacher education on STEM subjects resides in the transfer of pedagogic skills and affective experience from their own involvement in this course towards the design of activities for the classrooms in which they teach STEM subjects. Participants emphasised the intrinsic potential of some of the activities they experienced to be transferred verbatim to their own classroom. In other cases, it was necessary to contextualise the problem. As reported by one of the participants, they intended to “apply [the modelled experiment] but in a less complex way for preschool children.” What is predominant, in any case, is the idea of transferring the experiential spirit, and the pedagogical model described above: student-centred, active, problem-solving based, and enjoyable.

Next, in order to exemplify the interaction between teachers and their involvement in the activities, we present the analysis of a transcript of a video recording of the work of a small group using a ramp.

Transcript Analysis of a Video-Recorded Session

In this transcript teachers are sliding a toy car through an inclined plane. The toy car slides mainly on a straight line, but eventually skids out of the way towards the left side. The camera turns to the left to focus on another team which has constructed a guarded lane with small cotton balls, so that the car toy does not slide out of its way.

[Figure 1 near here]

Transcript 1. A car toy following a straight line

F1: Female teacher 1

F2: Female teacher 2

M1: Male teacher 1

M2: Male teacher 2

1. F1: *The wheel is hurt / get another one / get... (inaudible) little wheel / that is / this wheel does not give.*

[Figure 2 near here]

2. F2: *Let's see* (female partner takes the wheel toy).

[Figure 3 near here]

(A male participant from another group gets close to F1).

3. M1: *What did you put this here for?*

[Figure 4 near here]

4. F1: *So that the toy car does not get derailed //* (she moves her hand towards the right, simulating a derailment towards that side).

[Figure 5 near here]

(Another male participant hands in a new car which has been tested by him in the back part of the room).

5. M2: *Look at this*

[Figure 6 near here]

6. F2: *Does it give everything?* (another female participant of the group asks F1 – F1 tries the wheels of the new car sliding them on the palm of her left hand).

[Figure 7 near here]

(F1 slides the car toy on the inclined plane, so that the car moves in a straight line without stopping and falling at the end of the table. The camera focus briefly on the activity of the other groups).

[Figure 8 near here]

Analysis of transcript and activity

Teacher participants in the activity are working together in small groups. This specific group is gathered around a long table where they have placed a strip of cardboard as an inclined plane. Within this strip, there is a narrower lane signalled with cotton balls on both sides, so that the toy car can move through a straight line without leaving the lane. One of the female teachers is examining the toy car, testing the wheels as she rubs them on the palm of her hand. While doing this, she mentions that one of the wheels is “*hurt*”. She adds that “*this wheel does not give*”, suggesting that the wheel is stuck, not giving itself in the movement it should follow. It is interesting to note the analogy with a sick body. “*Let’s see*”, a female colleague grabs the toy car. Simultaneously, a male colleague from another team gets close to F1 and asks her on turn 3, “*What did you put this here for?*” while pointing to the cotton balls. It is interesting to note the attention these cotton balls get from M1 as the arrangement of participants establishes a clear boundary between groups, so that participants can negotiate together within each group about their own way to design an experiment involving an inclined plane, as well as making their own hypotheses before trying each of their toy cars. Nevertheless, the design of the lane made of cotton balls is apparently attractive enough to get the attention of M1 and get him involved in the business of another team. Heath and

colleagues (2008) have highlighted the challenges for mutual engagement and co-participation in activities at science museums, yet these teacher participants seem to get as motivated as required to trespass the boundaries of another group and get involved in their design for the experiment using an inclined plane and a toy car.

Both the materiality of the objects (Hetherington and Wegerif, this volume) involved in the experiment and the rules of participation involving an open-ended task seem to exert a strong effect on the expression of creative solutions and interest on the work of others (Fernández-Cárdenas 2008; Fernández-Cárdenas and Silveyra-De La Garza 2010). In addition to this, it is worth noting how simultaneously M2 is looking inside a plastic bag for alternative options of car toys, and testing them in another table sliding them in the surface of such table. He also seems to be crossing boundaries, working in another table, using resources that are not located in the territory of his group.

Eventually, after testing toy car candidates on the table, M2 seems to identify a suitable car for the experiment and grabbing it moves his body through the conversation of F1 and M1, reaching F1 and asking her to look at the car in the palm of his hand. This move incurs in a rupture (Schegloff 1992) of the flow of the sequence of turns between M1 and F1. However, he seems not to care about this and passes the car to F1. F2 is paying attention to this and asks F1 in turn 6 “*does it give everything?*” Again, it is interesting to note the bodily analogy relating to the car, and the spontaneous involvement of a fourth participant in this unfolding course of cooperative action. Next, F1 lets the car slide freely on the inclined plane. This analogy, and the way teachers interact, shows they are involved in the joint solution of the problem and, at the same time, they use a childlike behaviour playing a game. These results agree with those of Bell et al. (2009) in relation to similar activities encouraging teachers to be creative and spontaneous.

Triangulation: The perspective of participants

From the sources analysed and presented in this article, it is possible to see the high level of engagement of teachers in service as part of this CPD workshop. Participants construct their own trajectories as well as sequentially interacting, making predictions, testing hypothesis, and deciding together about the aspects affecting velocity and trajectories of toy cars and trucks. Teachers reflect on their own involvement creatively so that they propose the transfer of their experience to the design of lessons for their own school classrooms. The data shows how the enthusiasm of participating in an inspirational setting with playful activities is constructive for imagining alternatives for their school students. Data also describes the emergence of a new confidence gained for dealing with STEM subjects in pedagogic situations, and new possibilities for helping their students to interpret what is going in a given attempt for solving a problem using a STEM approach to scientific education. Finally, the data gathered in terms of enthused testimonies and constructive conversations helps to map trajectories which are transformative for the identities of the participants. In other words, they start participating in a more rigid and insecure fashion and end up as enthused participants with a more robust comprehension of the affordances of a STEM approach for solving problems that can be even located in their own community.

Discussion and conclusion

Museums and other non-formal educational settings provide an excellent opportunity for participants to get engaged in scientific activities, appropriating them in a playful manner. In particular, teachers in the analysed session of this CPD workshop were guided in their

participation in order to construct scientific knowledge about the use of inclined planes and the impact on velocity of vehicles. We can now revisit the suggestions proposed by Schauble et al. (1997), by defining three organising themes for studying the relationship between museums and scientific education:

(a) Learning and learning environments: Teachers had the opportunity to negotiate the validity of their predictions and get involved in the knowledge of inclined planes as simple machines with everyday uses and situated examples. They also had the opportunity to reflect on the pedagogy that can be better used in their own classrooms.

(b) Interpretation, meaning, and explanation: These pedagogic elements are coupled with an emotionally positive atmosphere in which teachers were feeling free to participate without evaluation outside restrictive environments. Specifically, we consider that this has generated a relationship between collaborative work, a playful environment, and the need to perform an intellectually demanding task in which assertions must be supported by establishing relationships between different aspects of a phenomena and concrete evidence. This combination has afforded relevant learning experiences for teachers for the use of a STEM perspective in their own classrooms.

(c) Identity, motivation, and interest: We suggest that this hands-on experience for constructing scientific knowledge, and all the atmosphere around participants, was more powerful than the usually more theoretical courses teachers have as formal training on science education. The situated and dialogic experience they had at the museum was reported as one of the first opportunities teachers had an authentic involvement in these topics.

Our results help to confirm the relevance of non-formal educational experiences for the construction of knowledge and identities which are usually not afforded by schools and institutions formally designed for teacher education. In this sense, museums in

Mexico could play a significant role in CPD courses for educating teachers and in the construction of a STEM culture in schools.

References

- Barahona, A., J. Chamizo, A. Garritz, and J. Slisko. 2014. "The history and philosophy of science and their relationship to the teaching of science in Mexico." In *International Handbook of research in history, philosophy and science teaching*, edited by Michael R. Matthews, 2247- 2269. New York: Springer.
- Bell, D. V. J. 2016. "Twenty-first Century Education: Transformative Education for Sustainability and Responsible Citizenship". *Journal of Teacher Education for Sustainability*, 18 (1): 48–56. doi:10.1515/jtes-2016-0004.
- Bell, P., B. Lewenstein, A. Shouse, and M. Feder, editors. 2009. *Learning science in informal environments: People, places and pursuits*. Washington, DC: The National Academies Press.
- Bhabha, H. K. 1994. *The location of culture*. London: Psychology Press.
- Calixto Flores, R. 2004. "Formas de explicación del proceso de respiración de las plantas" [Forms of explanation for the breathing process of plants]. *Perfiles Educativos*, 26 (105-106): 125-142.
- Castanheira, M. L., T. Crawford, C. N. Dixon, and J. L. Green. 2001. "Interactional ethnography: An approach to studying the social construction of literate practices". *Linguistics and Education* 11 (4): 353–400.
- Clifford, V., and C. Montgomery. 2015. "Transformative Learning Through Internationalization of the Curriculum in Higher Education". *Journal of Transformative Education* 13 (1): 46–64. doi:10.1177/1541344614560909.

Colucci-Gray, L., E. Camino, G. Barbiero, and D. Gray. 2006. "From Scientific Literacy to Sustainability Literacy: An Ecological Framework for Education". *Science Education* 90 (March): 227–52. doi:10.1002/sce.20109.

Dewey, J. 1909. *Moral Principles in Education* / [The Project Gutenberg eBook of Moral Principles in Education]. Cambridge, MA: Houghton Mifflin Co.
<http://www.gutenberg.org/files/25172/25172-h/25172-h.htm>

Dierking, L. and L. M. Martin. 1997. "Guest editorial: Introduction." *Science Education* 8: 629–631.

Dierking, L. and J. H. Falk. 1994. "Family behavior and learning in informal science settings: A review of the research." *Science Education* 78 (1):57–72.
<http://doi.org/10.1002/sce.3730780104>

DiGiacomo, D. K., and K. D. Gutiérrez. 2016. "Relational Equity as a Design Tool Within Making and Tinkering Activities". *Mind, Culture, and Activity* 23 (2): 141–53. doi:10.1080/10749039.2015.1058398.

Dillon, J. 2016. "50 Years of JBE: From Science and Environmental Education to Civic Science". *Journal of Biological Education* 50 (2): 120–122.

Falk, J. H., and L. D. Dierking. 2000. *Learning from museums: Visitor experiences and the making of meaning*. Oxford, UK: Altamira Press.

Falk, J. H., and L. D. Dierking. 2013. *The museum experience revisited*. London: Routledge.

Feher, E. and L. Rennie. 2003. Guest editorial. *Journal of Research in Science Teaching* 40 (2): 105–107.

Fernández-Cárdenas, J. M. 2008. "The Situated Aspect of Creativity in Communicative Events: How Do Children Design Web Pages Together?" *Thinking Skills and Creativity* 3 (3): 203–216.

Fernández-Cárdenas, J. M. and M. L. Silveyra-De La Garza. 2010. "Disciplinary knowledge and gesturing in communicative events: a comparative study between lessons using interactive whiteboards and traditional whiteboards in Mexican schools". *Technology, Pedagogy and Education* 19 (2): 173–193.

Fernández-Cárdenas, J. M. 2014. "El Dialogismo: Secuencialidad, Posicionamiento, Pluralidad e Historicidad en el Análisis de la Práctica Educativa" [Dialogism: Sequentiality, Positioning, Plurality and Historicity in the Analysis of Educational Practice]. *Sinéctica*, 43:183–203.

Fernández-Limón, C. 2014. "2° Estudio de Seguimiento. Diplomados Infantiles" [Second follow-up study. Children's certificates]. Educational Assessment 2. Monterrey, México: hornos³.

Flores-Camacho, F., L. Gallegos-Cázares, X. Bonilla-Pedroza and F. Reyes-Cárdenas. 2007. "Influencia que ejercen la formación y el medio al conformar las concepciones sobre la naturaleza de la ciencia en profesores de ciencias de secundaria" [Influence exerted by formation and environment for conforming conceptions about the nature of science in secondary school teachers]. *Anuario Educativo Mexicano: Visión Retrospectiva*, 179 – 214. México: UPN- Miguel Ángel Porrúa - Cámara de Diputados del H. Congreso de la Unión.

Gallegos, L., B. García and L. López. 2005. "Los conceptos básicos de los profesores(as) de biología de secundaria: resultados de una muestra nacional" [The basic concepts of biology in secondary school teachers: results of a national sample]. *Memorias Electrónicas del VIII Congreso Nacional de Investigación Educativa*.

García Franco A., F. Reyes Cárdenas, F. Flores and L. Gallegos. 2006. “Conocimientos básicos de profesores mexicanos de química de secundaria” [Basic knowledge of Mexican secondary school teachers in Chemistry]. *Educación Química* 17 (3): 379–387.

García Ruiz, Mayra and Beatriz Sánchez Hernández. 2006. “Las actitudes relacionadas con las ciencias naturales y sus repercusiones en la práctica docente de profesores de primaria” [Attitudes related to natural sciences and their repercussions on teaching practices in primary school teachers] *Perfiles Educativos* 28 (114): 61-89.

García Ruiz, M. and L. Orozco Sánchez. 2008. “Orientando un cambio de actitud hacia las ciencias naturales y su enseñanza en profesores de educación primaria” [Orienting a change in the attitude towards natural sciences and their teaching in primary school teachers]. *Revista Electrónica de Investigación Educativa* 7 (3): 539-568.

Gee, J. P., and J. L. Green. 1998. “Discourse analysis, learning, and social practice: A methodological study”. *Review of Research in Education* 23: 119–169.

Gómez Galindo, A. A., A. García Franco and C. García González. 2013. “Estado de la Investigación en Educación en Ciencias Naturales, en el Nivel de Educación Básica, durante la década 2002 al 2011” [State of the research in natural sciences, for the level of basic education during the decade 2002-20011]. In *Una década de investigación educativa en conocimientos disciplinares en México (2002-2011): matemáticas, ciencias naturales, lenguaje y lenguas extranjeras* [A decade of educational research in disciplinary knowledges in Mexico (2002-2011)], edited by Alicia Ávila, Alma Carrasco Altamirano, Alma Adrianna Gómez Galindo, María Guerra Ramos, Guadalupe López Bonilla and José Ramírez Romero, 165-202. México: COMIE-ANUIES.

Goodwin, C., and J. Heritage. 1990. “Conversation analysis”. *Annual review of anthropology* 19: 283–307.

Goodwin, C. 2017. *Co-Operative Action*. Learning in Doing: Social, Cognitive and Computational Perspectives. Cambridge: Cambridge University Press.

Goodwin, C. 2007a. "Interactive footing". *Studies in Interactional Sociolinguistics* 24: 16.

Goodwin, C. 2007b. "Participation, stance and affect in the organization of activities". *Discourse & Society* 18 (1): 53–73.

Guerra-Ramos, M., J. Leach and J. Ryder. 2005. "The nature of scientific enquiry as a topic of teaching in primary science: curriculum expectations, teachers' ideas and implication for teachers' education." ESERA, Barcelona: Spain.

Guerra-Ramos, M., J. García-Horta, D. López-Valentín, A. A. Gómez Galindo, and R. Balderas-Robledo. 2011. "Science teachers' attitudes and perceptions related to practical work: a self-report questionnaire." *E-Book Proceedings of the ESERA Conference: Science learning and Citizenship*, 94-98.

Gutierrez, K. D., and S. Vossoughi. 2010. "Lifting Off the Ground to Return Anew: Mediated Praxis, Transformative Learning, and Social Design Experiments". *Journal of Teacher Education* 61 (1–2): 100–117. doi:10.1177/0022487109347877.

Gutiérrez, K. D. 2008. "Developing a Sociocritical Literacy in the Third Space". *Reading Research Quarterly* 43 (2): 148–64.

Hatch, E., and C. Brown. 1995. *Vocabulary, Semantics, and Language Education*. Cambridge: Cambridge University Press.

Heath, C. and D. vom Lehn. 2008. "Configuring "Interactivity": Enhancing Engagement in Science Centres and Museums." *Social Studies of Science* 38 (1): 63–91.

INEE. 2015. Los docentes en México. Informe 2015. [Teachers in Mexico. Report 2015]. México: INEE.

Kazak, S., R. Wegerif, and T. Fujita. 2015. "The Importance of Dialogic Processes to Conceptual Development in Mathematics". *Educational Studies in Mathematics* 90 (2): 105–20. doi:10.1007/s10649-015-9618-y.

Lave, J., and E. Wenger. 1991. *Situated learning: legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lucas, A. M. 1991. "Info-tainment and informal sources for learning science." *International Journal of Science Education* 13 (5): 495-504.

Rennie, L., E. Feher, L. Dierking, and J. Falk. 2003. "Toward an Agenda for Advancing Research on Science Learning in Out-of-School Settings." *Journal of Research in Science Teaching* 40 (2): 112–120.

Robinson, K. 2010. *Changing Education Paradigms*. London: Royal Society for the encouragement of Arts, Manufactures and Commerce. Accessed 21 October 2015. <https://www.youtube.com/watch?v=zDZFcDGpL4U&spfreload=10>

Reyes Angona S., and J. M. Fernández-Cárdenas. 2015. "La escritura académica en la formación en línea de docentes de escuelas públicas mexicanas" [Academic writing in the online formation of teachers in public Mexican schools]. *Revista Electrónica de Investigación Educativa* 17 (2): 1–15.

Reyes Angona S, J. M. Fernández-Cárdenas, and R. Martínez Martínez. 2013. "Comunidades de blogs para la escritura académica en la enseñanza superior. Un caso de innovación educativa en México" [Communities of blogs for academic writing in higher education: A case of educational innovation in Mexico]. *Revista Mexica de Investigación Educativa* 18 (57): 507–35.

Rogoff, B., M. Callanan, K. D. Gutiérrez, and F. Erickson. 2016. "The Organization of Informal Learning". *Review of Research in Education* 40 (1): 356–401. doi:10.3102/0091732X16680994.

Sakar, L. (29 January 2016). Harmony STEM Program. (C. Fernández, Interviewer)

Salinas, P., E. Quintero and J. M. Fernández-Cárdenas. 2016. "Fostering Dialogue in the Calculus Classroom Using Dynamic Digital Technology". *Digital Experiences in Mathematics Education*, 2 (1): 21–49. <http://doi.org/10.1007/s40751-016-0013-9>

Schauble, L., G. Leinhardt, and L. Martin. (1997). A framework for organizing a cumulative research agenda in informal learning contexts. *Journal of Museum Education* 22: 3–8.

Schegloff, E. 1992. "Repair after next turn: The last structurally provided defense of intersubjectivity in conversation." *American journal of sociology* 1295–1345.

Stocklmayer, S., L. Rennie and J. Gilbert. 2010. "The roles of the formal and informal sectors in the provision of effective science education." *Studies in Science Education* 46(1):1-44, DOI: 10.1080/03057260903562284

Simmons, P. and V. Lunetta. 1993. "Problem-solving behaviour during a genetics computer simulation: Beyond the expert/novice dichotomy." *Journal of Research in Science Teaching* 30: 153-174.

Skukauskaitė, A., Y. Liu, and J. L. Green. 2007. "Editorial introduction: Logics of inquiry for the analysis of video artefacts: Researching the construction of disciplinary knowledge in classrooms". *Pedagogies: An International Journal* 2 (3): 131–137.

Sutton, R. and K. Wheatley. 2003. "Teachers' emotions and teaching: a review of the literature and directions for future research." *Educational Psychology Review* 15(4):327-358.

Wegerif, R. 2017. "Technology and teaching thinking: Why a dialogic approach is needed for the twenty-first century". In *The Routledge International Handbook of Research on Teaching Thinking*, edited by Rupert Wegerif, Li Li, and James C. Kaufman, 427–40. London: Routledge.

Wenger, E. 2010. “Communities of Practice and Social Learning Systems: The Career of a Concept”. In *Social Learning Systems and Communities of Practice*, 179–198. Springer, London. doi:10.1007/978-1-84996-133-2_11.

Tables and Figures

Table 1. Statements indicating learning with enjoyment

Statements from questionnaires
“We practice different topics in a different and fun way”
“It made us reflect in a fun way”
“Very entertaining and fun to use in the classroom”
“Very motivating and creative” [regarding activities]

Table 2. Lexical frequencies of terms used for answering the question: What do you think of the session?

Word	Frequency
Applying (and lexical variations such as “application” and “applied”)	11
Activity (and derived plural forms such as “activities”)	9
Practice (and derived adjectives such as “practical”)	5

Table 3. Statements about the visualization of science as applied knowledge oriented to practical activities.

Example	Comment
“Engineering is a vital tool”	It highlights the condition of engineering as applied science and not as pure hypothetical informative content or knowledge.
“due to the experiments we elaborate”	The chosen verb “elaborate” in first person highlights the active involvement of the subject in such experiments, not only as an observer but also as a constructor of knowledge.
“It was experimental, which makes us build our learning”	Awareness of learning as the product of experience, from the action or construction from the subject, and not only as an acquisition or mental reflection.

Table 4. Statements related to the perception of a problem-solving pedagogy.

Statement	Comment
“[the session was] very dynamic, allowing people to try it is a good way to study great topics”	Participants experience the session as something that is “tested”, and goes through a comprehensive experience and sensorial subjectivity, not only as an intellectual activity.
“The activity was really dynamic and applied a process accordingly to the team”	Flexibility in the establishment of activities. The learners “arrange” and contextualize the contents.
“It allows involving all the students and mobilizing their learning”	It highlights the central role and participation of the subject in the activity.

Figure 1. Context of the situation



Figure 2. The wheel is hurt



Figure 3. Let's see



Figure 4. What did you put this here for?

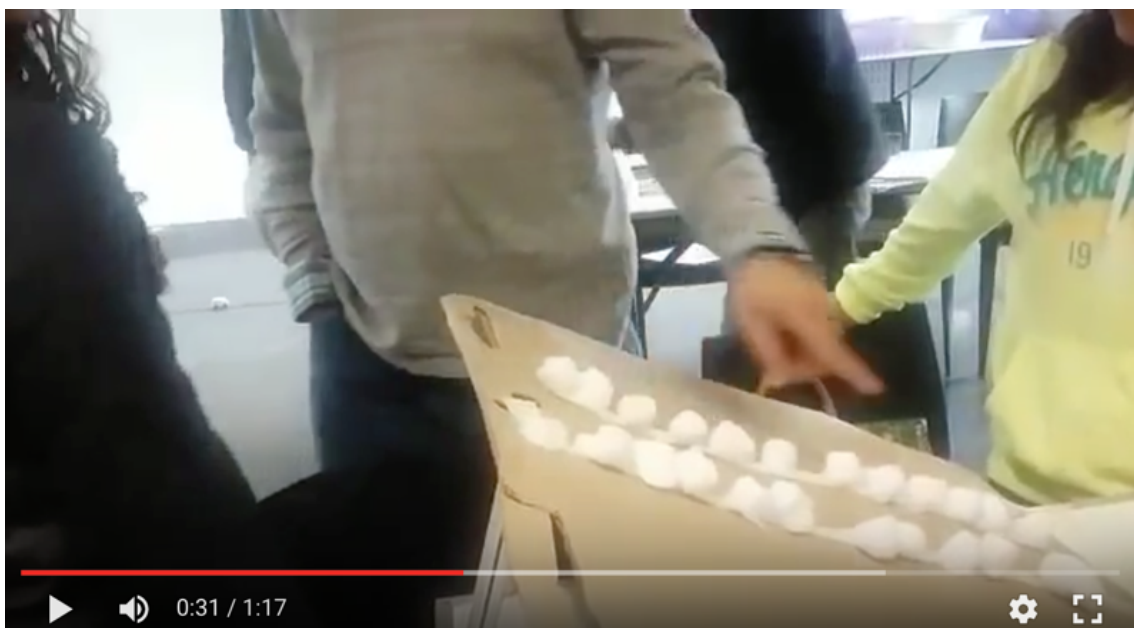


Figure 5. Toy car protection



Figure 6. Look at this



Figure 7. Wheel testing



Figure 8. Car sliding

