From experience to theory: Science recreation workshops as a practice-led approach in informal environments for science learning

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Abstract
Science recreation workshops (SRWs) create dynamic experiences in which participants discover, explore and understand natural phenomena. This serves as a unique and valuable means of the public communication of science and technology and informal science education activities, with the public at the centre of the process. To achieve this, SRWs integrate action and reflection not as a dichotomy, but as a complementary relation in which sensorial interaction is not a thoughtless process and mental activity is not disembodied. In this way, SRWs create virtuous cycles of meaningful learning.

However, SRW practitioners thus far have not paid enough attention to the development of a theoretical foundation to support their strategies; they remain highly dependent on empirical experience and tacit knowledge. The little attention paid to the creation of a conceptual framework represents a critical barrier for reflection, discussion and, with them, the maturation of the SRW community.

This work links a characterization of the SRW, built upon empirical experiences, to a variety of learning theories to identify an essential basis for discussion on the subject. Our objective is to complement the rich empirical tradition of the SRW with analytic elements intended to encourage discussion and promote—as tends to happen in activities with the public—virtuous cycles of theory and practice.

Keywords
Science recreation workshops, public communication of science and technology, informal science education, experience-based science activities

1. Introduction
Science recreation workshops (SRWs) are collective activities in which participants build science-related experiences based on three levels of interaction:

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physical, intellectual and emotional (García-Guerrero and Lewenstein, 2020). The public becomes a protagonist in a dynamic that shows science as both a process (method) and a result (accumulation of knowledge), which relates to the ideas of Dewey (1910) and Merton (1973). One of the main features of this approach is the possibility to adjust, in real time, to the participants’ needs and interests while allowing them to explore, discover and reach conclusions on their own—without having to trust the authority of experts (García-Guerrero, 2008).

SRW practitioners often ask why they do not receive more support for their endeavours. It is a valid question, but a better one would be: What have SRW practitioners done to deserve more support? They are convinced that their activities are interesting, amazing and even laudable, but we have to ask whether the quality of reflection and formal discussion of their job is on par with their practice.

SRWs, as a means for the public communication of science and technology (PCST), emerged in the late 1970s and early 80s as a result of initiatives by science enthusiasts who wanted to engage in outreach activities using scarce resources. Unlike other means of PCST (such as magazines and museums), which started with amateur initiatives but evolved into well-established institutions, SRWs are mostly developed by informal organizations. Most work is performed by volunteer groups (integrated by students), although several museums, schools and research centres incorporate them as a complement to their main activities.

In the past, this perceived lack of formality in the work of SRW groups—compared with other institutions—resulted in some degree of misinformed contempt from parents of volunteers who wanted their offspring to spend time in something ‘more productive’, teachers demanding that their students stop wasting time in SRWs and concentrate in class, schools not being open to letting groups develop activities with their students, and funding agencies not willing to provide support for SRW projects. Even if the past decade has brought a new sense of value for this kind of activity, the work done to support and legitimize SRW organizations remains inadequate.

Even if groups interact on an informal basis to share experiences and discuss their practice, that discussion has resulted in a scarcity of explicit materials that serve both as a reference for practice and as a framework for discussion. The community of SRW practitioners lacks what Wenger (1999) calls complementarity between participation and reification, which is effective feedback between practice and reflection. Practitioners need to engage in discussion to build coordinated meanings that reflect their enterprise—reifications of their work, or paradigms, in the language of Kuhn (1971)—and then promote more participation to interpret, produce and use that reification.

In this article, we provide a review of science communication and learning approaches that are useful to establish a foundation for the analysis of SRWs. Our discussion starts with informal environments for science learning as the broad category to which SRWs belong. We then use contributions that address them from an empirical perspective to recognize the essential features of the SRW. Once we have that initial structure in hand, our focus turns towards learning theories that can provide a conceptual basis for making sense of the way these activities work. Our goal is to build a framework that serves as an initial basis for the analysis and discussion of SRWs.

2. Informal environments for science learning

SRWs are situated at an interesting intersection: They develop informal science education (ISE) activities and are a means of PCST. This is not an uncommon circumstance. Ellenbogen (2013) claimed that there is an important affinity between the two fields. Even if several PCST practitioners reject the idea of learning as one of their goals, it is indisputable that the public learns in the process, and a number of practitioners do pursue the objective of learning (Lewenstein, 2011). Hence, following Bell et al. (2009), we use the term ‘informal environments for science learning’ (IESLs) to designate the convergence of the two concepts.

IESLs incorporate all activities independent of the school curriculum (Hofstein and Rosenfeld, 1996), which means that they account for most of what people learn about science in their lives (Falk et al.,
They involve participants of all ages and cultural and socioeconomic backgrounds and are typically characterized as participant-motivated, guided by their interests, voluntary, emotionally satisfying, personally rewarding, ongoing, contextually relevant, collaborative, non-linear and open-ended (Bell et al., 2009; Bonnette et al., 2019; Falk and Dierking, 2000).

A review of the literature on IESLs (Bell et al., 2009; McCallie et al., 2009; Fenichel and Schweingruber, 2010; Lewenstein, 2013; Kim and Dopico, 2016) reveals references to a wide variety of activities—mentorship, scientific texts, expert talks and lectures, science cafes, museum exhibits, zoo and aquarium visits, educational videos, science clubs, citizen science programmes—but there is no specific mention of anything resembling SRWs. However, the literature still refers to several features that fit SRWs well, such as increasing participant interest, involvement and knowledge, as well as promoting inquiry, enjoyment and a sense of science learning being personally relevant and rewarding (McCallie et al., 2009; Fenichel and Schweingruber, 2010).

In addition to these goals, shared by all IESLs, we can add a process-driven objective:

For my own part, I have a stock formulation: I deeply believe that the world would be a better place if more people had access to the kind of reliable knowledge about the natural world that people we call ‘scientists’ produce. I would like to contribute to improving that access. My own research, and that of many of my colleagues in the general area of science and technology studies, suggests that improvement will come when ‘we’ stop focusing exclusively on delivering information about particular scientific findings, and instead help more people understand the complex social process through which information and observations become ‘reliable knowledge’. (Lewenstein, 2011)

This puts even more emphasis on the practice—experience relation inherent in SRWs to address the nature of science: the values and beliefs necessary for the development of scientific knowledge, or science as a way of knowing (Quigley et al., 2011). To achieve the aforementioned goals, for IESLs (in general) or SRWs (in particular), it is important to understand that there is no generic formula that is effective for all kinds of participants. Moreover, there is no such thing as the general public; in reality, ‘the public’ is a very heterogeneous group, as multifaceted and unpredictable as the individuals who compose it (Burns et al., 2003).

If we define communication as ‘the practice of producing and negotiating meanings, a practice which always takes place under specific social, cultural and political conditions’ (Schirato and Yell, 2000: 1), we have to consider that the same practice may have a different meaning for each person depending on their context. In practice, engagement may have patterns, but it is in the interaction of such patterns and participants that the experience of meaning arises (Wenger, 1999). To work as a community, and not just as a collection of isolated individuals, negotiation is important. That does not mean that arriving at an agreement is obligatory, but participants have to try to understand one another.

This is why IESLs are highly dependent on context and require the ability to adjust depending on the participants’ situation. It also shows the source of critiques for events or programmes that fit into what is called the ‘deficit model’ of science communication: initiatives directed at filling ‘holes’ in the public’s scientific knowledge in the hope that it receives the message in the same way that the message was sent/intended (Durant, 1999; Lewenstein, 2003; Bubela et al., 2009; Stocklmayer and Rennie, 2017). This makes the implicit assumption that access to the same information is identical to drawing the same meaning and opinion from it, regardless of the subject.

On the opposite end of the spectrum, the ‘public engagement model’ builds on an essential fact: different audiences, with diverse backgrounds and experiences, derive different meanings from the same process (Stocklmayer and Rennie, 2017). It also recognizes the need for a diversity of voices, other than science experts, for successful communication processes. This results in a multidirectional dialogue with mutual learning, which allows people with varied backgrounds and scientific expertise to articulate and contribute their perspectives, ideas, knowledge and values in response to scientific questions or science-related controversies (McCallie et al., 2009).

However, as Einsiedel (2008) and Lewenstein (2011) have shown, there is no need to understand
things as such a ‘black or white’ dichotomy—one of either deficit or dialogue. There are situations, such as public health campaigns, in which deficit-like strategies work best, and other cases, when looking to solve local problems, that require public engagement. In most cases, a mixture of the two models is used within a continuum of participation. Even for participant-centred activities like the SRW, we have to bear in mind that some processes demand that the mediator provide information directly, even if we aim for the activities to be as engaging as possible for participants. With reference to this kind of process, we move on from the broad perspective of IESLs to a specific outline of the SRW in the next section.

3. Characterization of the SRW

The concept of the SRW emerged from the convergence of educational workshops and science recreation activities. For this purpose, workshops are considered places where several people work cooperatively to create something, or solve a task, while learning together in a practice-driven approach that requires observation, assimilation and emulation (Maya, 1996; Guile and Young, 1998; Falk and Dierking, 2000; Gajić and Milutinović, 2011). Science recreation has a dual meaning: enjoying the process of engaging with science while building new science-related experiences and knowledge; that is, recreating them (García-Molina, 2011; Lewenstein, 2013).

The SRW builds on the importance of creating appealing settings for participants to engage with science through three levels of interaction: physical, intellectual and emotional (Hofstein and Rosenfeld, 1996; Fenichel and Schweingruber, 2010; CSOSSL, 2015). Experiences in the SRW combine sensory, cognitive and social stimuli that enable a meaning-making process, assigning personal significance to the activity and the scientific elements associated with it (Bell et al., 2009). The key is to involve participants in a purposeful activity—a combination of acting and knowing, manipulating and thinking—that involves other people, leading to the creation of an inquiry community (Wenger, 1999; García-Guerrero, 2008; Moura et al., 2011; Pandya and Dibner, 2018).

One of the most powerful features of SRWs is that practitioners have the opportunity to adjust in real time to participants’ conditions, needs and interests (García-Guerrero, 2014), thus making the activities more appealing. This factor is critical, as established by Bonnette et al. (2019), in fostering participants’ interest to re-engage with science over time, which leads to repeated and deepening participation.

Despite several decades of work with the public and the development of successful methodologies, most SRW groups have not been able to turn their rich experience into meaningful conceptual tools. Such elements are essential for different situations: reflecting on their strategies and evaluating their performance, easing the creation and development of new groups, as well as achieving the reification of SRW practice into paradigms that can serve as the foundation for the community of SRW groups. To
establish an effective link between the reality of SRW activities and learning theories that can support their strategies, and build a deeper comprehension of how they operate, we address the essential stages in the development of SRW activities with the public. We support empirical references with the relevant elements of PCST and ISE, which, in turn, provide essential connections with the subsequent review of pedagogical elements.

3.1 Developing the SRW

For an activity to achieve the characteristics we have established for the SRW, with participants engaging with science as protagonists of a practice–reflection process, it cannot have a rigid structure, especially considering the wide variety of contexts and participants that we have to account for. Moreover, each practitioner should be able to put a personal touch on their workshops to enable better development, and try to enable participants to enjoy the process as much as possible.

Some general key points need to be considered for the SRW dynamic because the success of these activities is highly dependent on the structure and quality of the scheme (Gajić and Milutinović, 2011). In this section, we address the essential stages of the SRW with a combination of empirical experience (García-Guerrero, 2008; Gajić and Milutinović, 2011; García-Guerrero, 2014; Bonnette et al., 2019) and the support of a model of five broad personal responses to science that sets the purpose of PCST activities. Burns et al. (2003), in their widely recognized work, grouped these personal responses under the label AEIOU (the vowel analogy): Awareness of science; Enjoyment or other affective responses to science; Interest in science; the forming, reforming or confirming of science-related Opinions (or attitudes); and Understanding of science. With such a foundation, we identify six stages in the development of an SRW activity: introduction, exploration, active experience, questioning—reflection, discussion and conclusion.

a) Introduction. SRWs require trust for successful development. Participants must feel that they can rely on the mediator and can be comfortable with the community as a whole. That is why mediators have to introduce themselves to the community and emphasize that participants use their first name (or a catchy nickname), which helps establish the role of a partner instead of a teacher. It is important, if time allows, to invite participants to introduce themselves to help them establish an identity within the group.

Thus, when the moderator gives instructions, it is of crucial importance that he/she puts himself/herself in the children’s position and is aware of what has to be said, in what way and order, to make the instruction clear. Besides, the language of instruction has to suit children’s age as well, so it is a good practice to have a pair of moderators. (Gajić and Milutinović, 2011: 295)

b) Exploration. It is impossible to develop an SRW without a clear idea of the participants’ context regarding the topic at hand. We introduce a dual sense of the ‘Awareness’ in the AEIOU model: informing participants about what they are going to work with and exploring what they know about it. The mediator asks relevant questions to help determine the proper approach for the specific group—where to start, what kind of narratives could be useful, how deep to go, and so on—as well as to find previous knowledge that will lead to meaningful learning.

This diagnosis lets the mediator know whether the group is composed of what Burns et al. (2003) call the ‘lay public’ (uninformed or uninterested), the ‘interested public’ (informed on the subject) or the ‘attentive public’ (specialists). While the ‘lay public’ outnumbers the other two groups in most cases, it is rare to have a homogeneous group. Identifying informed or specialist participants plays a major role in getting them involved in the process as allies—by sharing their knowledge and experience and serving as experts that help others.

c) Active experience. Once the starting point has been established, it is action time. An effective way to get started is through sensory perception, leading to an intense personal experience influenced by emotions (Gajić and Milutinović, 2011). Usually, this is associated with ‘hands-on’ activities but can go considerably further to include seeing, hearing, smelling and even tasting things.
A fundamental part of the SRW is that, as long as it is safe for the participants, the action should be performed by them; otherwise, they are mere spectators watching some other person having fun. When handling large groups, it is best to break them into small teams (with enough material) to make interaction easier for everybody. This also helps to establish a competitive environment that encourages stronger engagement.

According to Burns et al. (2003), the essential idea here is to engage participants in an ‘Enjoyable’ practice; that is, to allow them to have fun while they face new aspects of the phenomenon they are encountering. That is why it is so important for the mediator to avoid performing demonstrations and explanations as much as possible, and instead let the participants explore, discover and sort things out for themselves.

d) Questioning–reflection. From the outset, we have repeated that SRWs promote the interaction between action and reflection, or practice and theory, and that the active experience would be empty without a stimulus to think about. For that, we use triggering questions that connect the experience of participants with the scientific issues we intend to address, and this leads to the ‘Interest’ part of the AEIOU model.

For Burns et al. (2003), if we manage to inspire people, they will choose to become involved in activities to seek more information. This is very important, as most IESL activities imply voluntary participation (they are not mandatory, as with school). This is why it is important to find the proper questions that can help us dispose people to engage with the workshop dynamic (Bonnette et al., 2019). Such interest will lead to a process of reflection in which participants make sense of their experience and prepare to share their ideas. It is worth noting that this part of the process is fluid: It can develop at any moment but reaches its highest point after the sensory interaction has led to pleasant and meaningful experiences.

e) Discussion. As a result of the previous step, the stage is set for participants to share and explain their perspectives on the phenomenon at hand. At first, the goal is for people to predict what will happen and explain their reasoning, analyse and discuss the ideas of their partners and try to negotiate meanings between them. Afterwards, they can make suggestions that lead to adjustments to the activity in creative ways, explain what happened and relate their experience to what is considered reliable knowledge of nature (Lewenstein, 2011). This is an important part of the process because the exchange among peers helps articulate, shape and enrich their experiences (Gajić and Milutinović, 2011). If the discussion does not flow, which happens often, the mediator must turn to trigger questions or provocative examples; and, if the group has a hard time achieving reliable knowledge, the mediator will have to help with that as well.

This step involves the ‘Opinion’ component of the AEIOU model. During discussions, participants share more than explanations, especially when addressing social issues or personal experiences related to science: They present their opinions. It is necessary to find the right balance between the participants’ discussion of their respective perspectives and respecting somebody else’s opinion. Sometimes, people (such as specialists and even mediators) try to impose their opinion on others—a line that should not be crossed.

f) Conclusion. Once the above stages have been completed, the community tries to reach some conclusions about the subject and discusses practical uses of what it has just worked with. This implies reaching the ‘Understanding’ component of the AEIOU model. The goal here is to connect the scientific issues at hand to the participants’ reality, helping them link their SRW experience (and the implicit knowledge) with their previous ideas to promote meaningful learning (Ausubel, 1968).

It is useful to let participants recapitulate what they have just experienced and learned by using narratives that serve to reassure knowledge (Cohen and Haden, 2015). Finally, the community should air some final questions and, instead of drowning them with direct answers, rephrase them to stimulate participants to find answers on their own. The idea is to send people with more doubts than certainties and let them know that this is what science is all about: the next question.

With the conclusion of the workshop, if it is successful, we might have planted a seed of curiosity in the participants to find out about more things: a need to know or desire to resolve any remaining uncertainties, which works as a basic human motive. To satisfy that curiosity, the participants might feel the need to
transition from early exposure to science to a sustained and well-developed interest (Bonnette et al., 2019). This provides the opportunity for more ambitious programmes involving SRWs.

### 3.2 Taking a further step

The main goals of ISE and PCST are to create interest in science through excitement, wonder and surprise, as well as for participants to develop knowledge and values that make their experiences relevant and meaningful (Fenichel and Schweingruber, 2010). All of this is associated with the concept of fascination, as described by Bonnette et al. (2019): a motivational construct that integrates interest, curiosity and mastery as goals. Fascination helps us capture an emotional and cognitive attachment/obsession with topics and tasks in science. Hence, successful SRW events have the potential to get participants more involved in science-related events. There is a need for follow-up programmes to avoid leaving participants on their own after positive initial experiences (García-Guerrero et al., 2019). As is the case with other ISE activities (Durant et al., 2016), SRWs provide an opportunity to connect interested participants with established learning communities or programmes, provided such spaces exist in a specific area.

Interestingly, SRWs can also provide the foundation for this kind of periodic approach that take things a step further: fostering closer relationships between science and the participants’ interests. Regular science programmes provide permanent free-choice learning opportunities for people (García-Guerrero et al., 2019). This involves participants taking up science as a hobby, learning about it, having a bigger choice in what and how they learn, and developing projects on their own (Lewenstein, 2013; Liu and Falk, 2014).

These kinds of programmes, or clubs, provide opportunities for participants to pursue deeper goals, to ‘seek more opportunities related to science, become aware of gaps in their knowledge, persist through closing challenging gaps, and gain pleasure from building competence, knowledge, and skills in science’ (Bonnette et al., 2019). There is evidence linking participation in periodic extra-curricular programmes to positive attitudes towards science, improved science learning and a greater sense of appreciation for scientific endeavours (Hartley, 2014). Although it is important to promote such endeavours, they have been addressed in detail elsewhere (Sahin, 2013; Vartianen and Aksela, 2013; Hartley, 2014; García-Guerrero et al., 2019). We must turn our attention to the learning theories that can provide a foundation for the discussion of SRWs.

### 4. Literature review of learning theories (learning arsenal)

In the original conception, workshops are spaces where artisans manufacture or repair specific goods. To achieve their purposes, those people require a certain skill at their craft, which can only be attained with practice but also requires a deep understanding of what they do. Here, we find the traditional model of apprenticeship, developed long before modern learning theories, implicit in workshops. It involves four elements: the apprentice as a learner, a fixed set of craft knowledge, the master as teacher, and the idea that the desired expertise is context bound and not conductive to transfer (Pratt, 1992; Guile and Young, 1998; Harrison and Grant, 2015).

Although the essence of the SRW breaks with the idea of a traditional teacher, and we have to recognize that scientific knowledge is not fixed, SRWs show classic elements of workshops, such as practice-led and context-bound learning. It is also noteworthy that SRWs have been developed independently of learning theories: They did not come to life as a result of pedagogic reflections. Nevertheless, SRW strategies seem to apply the ideas of several learning theories that can help us better understand how to promote experience-building processes around science and provide resources to face different challenges. As an analogy, García-Guerrero (2014) claimed that pedagogic theories could be viewed as some sort of ‘Batman’s belt’: Just like the utility belt that the fictional hero wears, they provide diverse tools that will never be used together in the same activity, but, at the same time, there is no single tool that (itself) will help face all possible situations. Hence, these theories give us resources to develop the SRW in a wide variety of contexts.
Rather than thinking of the possibility of a ‘best way’ to learn, we need to be aware of the great diversity in how people think and learn (Harel and Papert, 1991). To maximize participation, it is best to have the ability to adapt to the different ways of learning that we can find. With this in mind, we performed a literature review to look for pedagogic elements that can help build a foundation for SRW practice. In this section, we present the relevant elements of various approaches that contribute to our goal: behaviourism, cognitive development, social components, constructivism and constructionism, and discussion. We close with a broad scope of the ‘communities of practice’ theory that will help us shed a different light on the analysis of SRWs.

4.1 Behaviourism

Behaviourism, as a learning perspective, has taken as much criticism as the deficit model in PCST. It is easy to find descriptions of behaviourist practice that sound a lot like deficit theory: the educator as the indisputable agent whose task is to ‘fill’ learners with the contents of their narrations, which are just pieces of reality, disconnected from the totality that breeds them and the context in which they acquire sense (Freire, 1972).

Behaviourism takes learning as a process of forming connections between stimuli and responses (Bransford et al., 2000). Hence, the main concern is how an association between stimuli and responses is made, reinforced and maintained (Ertmer and Newby, 1993). In this perspective, there is someone (the teacher) who presents information in its final form for participants to memorize and be able to recite in the future (Ausubel, 1968; Freire, 1972).

This perspective prevailed in schools for a long time, with an imposition—from above and outside—of subject matter, methods of learning and behaving on learners (Dewey, 1986). However, we have to acknowledge that some things are almost impossible to learn without it. Such is the case with multiplication tables, the symbols for chemical elements and the names of subatomic particles. However, for the most part, it is important to discard the conception of learners as empty vessels that must be filled by transmitting information to them (Rodriguez, 2012); there is a need to understand the importance of logic and reasoning in learning. We thus turn to cognitive development.

4.2 Cognitive development

Jean Piaget was the pioneer of the cognitive analysis of learning, based on the inner structures of the minds of the learners, especially children. For Piaget (1967), mental development starts at birth and is comparable to organic growth—a march towards the final equilibrium of the adult spirit. Through the process of cognitive development, individuals go through stages that define the kinds of tasks a person can perform and solve (Piaget, 1964).

In this context, logic and reasoning are not innate attributes of human beings but features that must be created and fostered (SECT, 2001). Cognitive growth is not a given process, but depends on the stimulus the individual is subjected to. Every new experience triggers changes in the mental structures, adapting them to reality (Piaget, 1964; 1967).

With Piaget’s framework, a new possibility emerged: to discard the idea of learning as knowledge transmission and to work towards guiding children in acquiring their own knowledge through action and through trial and error as they attempt to assimilate new information into their existing understanding of the world (SECT, 2001). This shows an intrinsic relation between new experiences and practices and the mental structures of each individual. As Ausubel (1968: 18) puts it: ‘If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.’

According to Ausubel’s meaningful learning approach, people cannot learn something alien to their existing ideas and experiences. To achieve true understanding, the new information must have meaning for learners—it must link with their existing knowledge (Ausubel, 1968; Pozo and Gómez, 1998). It is important to start from the learners’ internal logic, considering their prior experiences and beliefs, to engage them in the learning process and get them to understand some of the meanings in scientific knowledge (Pozo and Gómez, 1998; CSOSSL, 2015).
We also have to account for the fact that not all existing knowledge is complete or scientifically sound. Educators have to pay attention to the incomplete understanding, false beliefs and naive renditions of concepts that learners bring with them in order to bridge the differences and try to achieve a more mature understanding (Bransford et al., 2000; Pandya and Dibner, 2018). Otherwise, the outcomes will be very different from what was intended.

From our discussion so far, it might appear that learning is an essentially individual process, but that is not the case. There is another important component—the influence of interaction with other people—which leads us to address the social side of learning.

### 4.3 Social components

The mind of the individual is not, as such, an individual mind. People participate in learning processes with a prior system of beliefs, knowledge, ideas, experiences and meanings that has been socially instituted (Dewey, 1958; Falk et al., 2012; Wehramann and Henze-Rietveld, 2016) and affects their abilities to remember, reason, solve problems and acquire new knowledge (Bransford et al., 2000). Even when people learn ‘alone’, reading from a book or having an independent experience, the meanings they construct are heavily context dependent. Most of the time, in either formal or informal settings, individuals get to understand something new while interacting with others. Therefore, learning is widely accepted as a fundamentally social process in which individuals learn from the collective, and the collective learns from individuals (Dalkir, 2005). Jerome Bruner stressed the importance of action and discovery in the process of learning, treating every cognition as a form of (social) construction (Gajić and Milutinović, 2011).

In contrast to Piaget’s individualistic approach, Lev Vygotsky worked on the social nature of learning. For him, any process of verbal interaction (talking) with others represents a stimulus for cognitive development (Garcia-Guerrero, 2014). This situates talk as a powerful social tool to build communities and help minds grow, as learners benefit from opportunities to reflect and share their ideas as part of the process of internalizing them (Resnick et al., 2010; King and Tran, 2017). The use of talk, reasoning and questioning relates to the concept of non-foundational knowledge that shifts responsibility away from the teacher as an expert and towards the participants as learners (Braund and Lelliott, 2017).

Perhaps the most important contribution Vygotsky made to our understanding of learning is the concept of the proximal development zone: the distance between the actual development of an individual, determined by their capacity for independent problem solving, and the level of potential development, determined through problem-solving under adult guidance or in collaboration with more capable peers (Vygotsky, 1980). This collaborative process helps learners perform certain tasks and serves as a means of developing new experiences, knowledge and abilities, which, when sustained, set off a virtuous cycle of cognitive development.

The goal of helping learners has given importance to the notion of ‘scaffolding’, in which a teacher or mediator provides temporary support that can be gradually removed as the learner grows (Guile and Young, 1998; Braund and Lelliott, 2017). While not explicitly calling it a scaffolding, for the specific case of science learning, Fenichel and Schweingruber (2010) proposed juxtaposing the participants’ understanding of a natural phenomenon with the formal disciplinary ideas that explain it, to help learners revise their ideas and see whether it is possible to approach current scientific understanding. However, we have to be careful. It is valid to seek to render the participants’ perspectives on a phenomenon coherent with reality, but we cannot impose our vision on them (Freire, 1972) or we risk turning them away. Mediators should attempt a dialogue to find common ground between different participants’ perspectives while using empirical results to validate their hypotheses. In addition to providing a comfortable learning environment, this will help show how science works in creating and validating theories that can explain natural phenomena.

### 4.4 Constructivism and constructionism

As stated above, participants get involved in learning experiences with specific sets of knowledge and experiences that shape their ideas, interests and motivations (Pandya and Dibner, 2018). This is the
reason why an event, such as an SRW, might have different meanings for each of the individuals involved. Even in deficit-like science communication processes, each person has a different interpretation of what was said because they internally build meaning according to their conditions.

Constructivism, in pedagogy, assumes that all knowledge is built upon a person’s prior ideas (Bransford et al., 2000; King and Tran, 2017) and seeks a balance between the influence of the social environment and internal cognitive features. From this perspective, knowledge is neither a copy nor a reflection of reality but is actively constructed by learners using physical and social interactions in an attempt to understand the world (Dalkir, 2005; Minner et al., 2010; García-Guerrero, 2014; Pandya and Dibner, 2018). The constructivist approach has an important imprint of the work of Dewey (1910; 1958; 1986) in highlighting the importance of play, experience and practice in the learning process (Halverson and Sheridan, 2014). It is possible to see this reflected in IESL activities that use inquiry-based and hands-on strategies to help participants with active thinking to build their own knowledge (Minner et al., 2010; Voussoghi and Bevan, 2013).

Taking a step forward, constructionism shares the aforementioned principles and proposes that the individual construction of knowledge goes deeper when the learner is consciously engaged in constructing a public entity or externalized product (Harel and Papert, 1991; Pandya and Dibner, 2018). In addition to Dewey’s contributions, contemporary research in neuroscience confirms the importance of tactical engagement and using our hands in the learning process (Dougherty, 2012; Pandya and Dibner, 2018). This has become a staple for several IESL movements, such as hands-on exhibits in museums, tinkering workshops (Gabrielson, 2015), the ‘maker movement’ (Dougherty, 2012), and, of course, the SRW. This approach allows the public to take matters into its own hands for a much higher degree of control over its knowledge, instead of being a passive recipient (Papavlasopoulou et al., 2017). Finally, participants make something shareable (Halverson and Sheridan, 2014; Gabrielson, 2015) in two senses: to let others handle the object, as well as to use it to discuss and debate topics in science, or even inspire others to participate.

4.5 Discussion

Most theories we have addressed, especially constructivism and constructionism, place a high value on practice as a motor for learning. Usually, it is easier to get participants involved in the physical part of practice (experimenting, tinkering and making) compared with the intellectual and emotional components (to complete the three levels of interaction). For this, as we saw in Vygotsky’s idea and other ideas on social learning, we have to appeal to oral communication: discussion.

Talk, as a direct exchange between humans who attribute intentionality and understanding to each other, is an essential tool for building communities (Resnick et al., 2010). SRW mediators have to be able to prompt talk in all kinds of contexts, for which they can utilize a variety of techniques useful to get participants involved:

1. Ask questions that link participants’ contexts to the issue at hand, to help them realize that they have valuable contributions to make to the community.
2. Repeat and rephrase learners’ contributions and emphasize particular comments (King and Tran, 2017) to help everybody get into the same line and encourage others to talk.
3. Even when answers have no apparent relation to the discussion, try to understand the logic behind the participant’s idea or a ‘spin’ that can get it along the conversation line. If participants feel that they have been shown as being wrong, it will be difficult to get them to talk again.
4. Let participants lead the route of discussion. The more they feel they have a choice in the process, the more they will get involved in it (Falk and Dierking, 2000).

In discussion within SRWs, we attach great importance to the idea of accountability in talk for the full development of learners’ abilities and dispositions for reasoned civic participation (Resnick et al., 2010). There are three essential aspects of accountable talk.

a) Accountability to the learning community. The mediator should make sure that the participants
listen to each other, ask each other questions and try to build arguments based on each other’s ideas.

b) Accountability to standards of reasoning. This involves participants making logical connections and drawing reasonable conclusions in arguments, and implies explanation, analysis and self-correction.

c) Accountability to knowledge. Perhaps the trickiest of the three, this involves ensuring that talk responds to proven facts and reliable sources. The importance of this aspect goes well beyond the SRW to lifelong learning, especially in an era when people need to identify what kinds of sources to trust.

4.6 Communities of practice

We have thus far addressed general aspects deriving from learning theories and have started identifying important relations among cognition, context and practice. As Guile and Young (1998) note, the process of learning involves changes in knowledge and action that are central to learning and developing new forms of practice. This leads us naturally to understand the SRW as a collective, practice-centred IESL, but one that lacks a fundamental theoretical foundation.

After establishing a general learning landscape, we can introduce an approach that fits the SRW almost perfectly: communities of practice (CoPs). Lave and Wenger (1991) started using the concept, in an intuitive form, in their studies on the learning processes of practitioners of different crafts—midwives, tailors, sailors, butchers, and even recovering alcoholics. Their conclusions led to a broader learning theory that contemplates all settings, even academic ones, where novices, or apprentices, need to get involved in the community’s social practices to develop a full domain of knowledge and skills (expertise).

Wenger (1999) used four premises to present the above approach: we are social beings, knowledge is a matter of competence (expertise) concerning valued enterprises, knowing is a matter of active engagement in the world, and meaning (our ability to experience the world and our engagement with it) is the ultimate product of learning. This shows a focus on learning as social participation, not just in the sense of local events but with the wider meaning of being active participants in the practice of social communities and constructing identities in those communities.

Wenger’s work uses the concept of identity to provide a major insight into integrating individualistic and collective learning in the CoP framework (and in the practice of SRWs). Building identity consists of negotiating the meanings of our experience while participating in social communities, serving as a link between the social and the individual, in which each can be talked about in terms of the other (Wenger, 1999). This avoids what he calls the ‘simplistic individual–social dichotomy’ without having to negate such a distinction. In this way, our perspective incorporates both the lived experience of the individual and the cultural–historical aspects of the social. By bringing together our experience and its social interpretation, we construct who we are in our negotiation of meaning (Wenger, 1999). This leads to the development of practice-linked (or domain-specific) identities and a sense of belonging, which happens in science clubs (as CoPs) that shape commitments to science learning (CSOSSL, 2015).

This is a major insight because SRWs perform collective processes in which we want to allow all participants to be protagonists, which seems like a contradiction. The concept of identity, and the construction of such an identity through practice in the SRW, gives a theoretical basis for the idea of collective protagonism in the community. Each participant plays a different and important role that makes him or her relevant within the group.

According to Wenger (2011), CoPs are formed by people who share a passion for something they do and regularly engage in a process of collective learning about it. They have three crucial characteristics, which we illustrate using the case of the SRW.

a) Domain. A CoP has an identity that arises from a common interest (the domain), being a member implies a commitment to developing a certain distinctive competence. The implicit stance here is that participants will share knowledge through their activities, discuss it and negotiate meanings to achieve the intended competence. The domain of the SRW is science, not only referring to knowledge but also to its history, practice, values, and even unresolved issues.
b) **Community.** Members’ collaboration (or mutual engagement) is key to the successful pursuit of their interests: They discuss, help one another and share information. This is the essential social dimension of CoPs and calls for the use of social learning as well as the constructivist and constructionist ideas addressed earlier. In an SRW, the participants’ input is more than welcomed: It is needed, and members encourage each other as they advance. That is how newcomers learn and become experts: by engaging with other members, being active in community events and taking on increasing responsibilities within their communities (Liu and Falk, 2014).

c) **Practice.** Sharing an interest is not enough for a CoP to exist; participants have to actually do something and socially interact while doing it. Herein lies a rupture with traditional dichotomies, which divide acting from knowing, manual from mental, and concrete from abstract, because engaging in practice always involves the whole person, acting and knowing at once (Wenger, 1999). To accomplish this, members of a community have a shared repertoire of resources: experiences, stories, materials, tools and ways to solve problems. The very essence of the SRW comes from participants playing with materials, doing experiments and solving problems in interactive processes of action and reflection.

Finally, we need to discuss reification: the process of ‘making into a thing’. Wenger (1999) refers to this concept as giving form to our experience by producing objects (or concepts) that shape it into something concrete. In this sense, reification is central to every practice: Any CoP creates abstractions, tools, symbols, stories, terms and concepts that can reify something of that practice in a congealed form. Reification, then, invites the participation of community members as they use, discuss and refute the meaning and worth of those reifications (Nolen and Ward, 2008).

In this article, we have worked towards the reification of the SRW, by using empirical experiences and ideas deriving from the community’s debates, to build a framework for further discussion and development of practice. However, debates stemming only from empirical notions, which have been around since the late 1990s (García-Guerrero, 2010; Garcia-Guerrero and Lewenstein, 2020), are not enough to consolidate a professional community for this specialty of IESL. That is why we have had to review learning theories (due to their link to practice) and find an approach to serve as the bedrock for discussion on SRWs. CoP theory provides the theoretical support that we have been looking for.

5. **Science recreation workshops as communities of practice**

Practice as a means of experience is the very reason for the existence of the SRW, and the set of resources to carry out SRW activities includes interaction, questioning, inquiry, narratives and problem solving. SRWs are closely linked with the characteristics of CoPs presented by Wenger (1999): They are essentially communities looking to build pleasant experiences through active practice while constructing knowledge about a specific scientific domain. However, the degree to which SRWs adopt a full CoP identity depends on their temporal duration and degree of participation, allowing us to distinguish among four situations: single events, periodical programmes, SRW groups and SRW analysis.

Before addressing the above situations in detail, we must emphasize that they are dynamic: People can move from one to another. Practitioners usually encourage participants from single events to join periodical programmes, and expert members of periodical programmes can rise to become apprentices in the SRW community. Finally, SRW groups have recently started encouraging their practitioners to be part of the professional discussion, whether in face-to-face events or web-based forums. This route to identity, with the possibility of achieving different levels of expertise to access the CoP in different situations, provides a set of possibilities to which novices are exposed as they build their own trajectories (Wenger, 1999).

a) **Single events (isolated practice).** This is the most basic form of engaging the public. It happens when SRW groups have a single-day event with first-time participants. In their initial experience with this kind of activity, the participants make up a small community mostly of novices, but with at least one expert (the mediator). It might be a bit shallow, as
most first-time science activities are, but it has the potential to be interesting and to arouse enthusiasm among the people involved (García and Meza, 2007; García-Molina, 2011; Cabral and Rivera, 2010).

The people involved constitute a miniature version of a CoP by interacting with materials, collaborating in different ways, negotiating meanings with each other and sharing information. While it has most of the features attributed to a CoP (Lave and Wenger, 1991; Wenger, 1999), it lacks the necessary regularity to allow for the development of certain expertise in the domain of science recreation. Thus, this can be seen only as a quasi-CoP.

Even if a single event does not achieve all the benefits of regularly engaging in practice, it presents the opportunity for initial learning experiences that have proven essential for supporting children’s interest in and motivation for science (Bonnette et al., 2019), and it becomes even more important because it is the gateway to the following situations.

b) Periodical programmes (basic practice).
Isolated experiences provide essential sparks of interest but cannot ‘keep the flame lit’. To foster a closer relation to science, they need subsequent follow-ups to flourish (García-Guerrero et al., 2019). To achieve deeper connections, there is a need for participants to replicate what they have done, reflect on it and discuss it with their peers (Robinson, 2019). There is a need for systematic activities—for people to go back regularly and grow their interests, knowledge and abilities.

Periodic participation in free-choice science programmes, such as science clubs, astronomy programmes, tinkering workshops and maker spaces, allows new members to enter the CoP as novices and gives them the opportunity for regular participation and engagement with other members of the community. Through practice, they can work their way to basic expertise in different aspects related to the domain of science recreation: handling materials, developing inquiry processes, understanding essential scientific principles, building devices, as well as clearly communicating ideas and results to others. This case is what we addressed as ‘taking a step further’ with the SRW to fully achieve the conditions to be considered a CoP.

c) SRW groups (committed practice). This is the case of the community within SRW groups, and it has the peculiarity of working towards making the first two situations possible. Its domain is the creation and development of SRW models and translating them into action in single events and periodical programmes. It means having a CoP that enables members to develop the abilities, knowledge and experience to create more CoPs, which demands that members work on two domains of expertise: on scientific knowledge and as SRW mediators. SRW practitioners have to achieve a minimum degree of knowledge on the topics they will address with the public. However, being adept at something is not just about knowing facts but about organizing knowledge into coherent frameworks and recognizing the relevance and potential application of knowledge in varying contexts (Pandya and Dibner, 2018). This kind of structured understanding allows for greater flexibility in learning and facilitates application across multiple contexts (Fenichel and Schweingruber, 2010). Only with a deep understanding will it be possible to relate to the broad spectrum of situations that different learners will pose.

Serving as a mediator in SRWs demands a basic knowledge of the fundamentals of the relevant activities (which we have addressed above) and a set of practical skills to develop them properly. Thus, people interested in becoming practitioners become apprentices in a workshop devoted to the development of SRWs and in a process in which they also contribute to the growth of their peers and the group as a whole. This is how the goal of developing SRWs contributes to a rich CoP—one that often feeds off former participants in isolated events and periodical programmes (Cabral and Rivera, 2010; García-Guerrero et al., 2019) to create new generations of practitioners.

Once people enter this kind of CoP, they participate in a safe environment of collaboration and cooperative learning. They are empowered to build knowledge, contributing their strengths to the group (and benefiting from those of others) while helping plan for how to better develop and explain specific activities (Robinson, 2019). Here, we find an excellent route for empirical growth in groups; the problem is that most of them spend too much time and effort to achieve what others have done before them, and very
few take the time to formally share the results of their experiences (García-Guerrero and Lewenstein, 2020). This poses a challenge to build and communicate the fundamentals of SRWs in order to help the advancement of the community of organizations dedicated to these activities.

d) SRW analysis (professional discussion).
Mimicking the ideas of Nolen and Ward (2008), we can say that the emerging community of specialists (practitioners and theorists) that discusses the SRW, as an object of study, is a CoP. In general, SRW practitioners already share experiences and argue about methodologies, mediators' training and the design of activities, but for the most part they do it informally and lack explicit documents resulting from such discussions. Some groups in Mexico have taken the initiative to publish books and academic articles to share their contributions and spark discussion (García-Guerrero and Lewenstein, 2020), but that remains an isolated effort. The professionalization of the SRW demands a broader participation in this process: Just as the success of an activity depends on the variety of voices and experiences involved, the analysis of SRWs needs broad participation to build, validate and use relevant ideas for their philosophy, methods, challenges and evaluation.

While the identity component of the CoP plays a fundamental role in all four situations described above, we want to highlight its impact on the creation and evolution of the professional SRW community. In this way, we have a perspective that allows for each group’s experience to be considered, as well as the cultural–historical aspects of the whole community. Each group can thus construct a stronger identity by bringing together its specific trajectories and social interpretation in the process of the negotiation of meaning. The groups recognize themselves as SRW professionals as they take part in the larger discussion that links their organizations and defines the paradigms for the community of groups. For example, in Mexico, the National Colloquium of Science Recreation (NCSR) has served as an essential forum to stimulate reflection and discussion on the SRW. The event started in 2016 and led to the creation of ‘Recreación en Cadena’, the Mexican Network for Recreative Science, which has kept the NCSR going yearly with an average of 40 papers and 100 participants (García-Guerrero and Lewenstein, 2020). Although this case is an important step forward, most presentations rely heavily on empirical knowledge and lack a theoretical foundation. The emergence of the NCSR, and the network behind it, demonstrates an opportunity to strengthen the work of this community of groups through a richer discussion that leads to a proper theoretical foundation for the SRW.

6. Conclusions

Our analysis of theories of learning allows us to highlight the importance of a contextualized approach to science learning. Maybe the most important feature of the SRW, one that sets it apart from most means of PCST and ISE, is its ability to integrate theory and practice. For the most part, this virtue has not been analysed properly, mainly owing to a lack of theoretical tools. The CoP model helps us understand how SRWs build CoPs around science, as a domain, that sets them off into virtuous cycles that allow for future growth, especially when it comes to the route of practice that evolves from isolated, to basic, committed and even professional approaches. There is an interesting path for the development of SRW experts, assuming that SRW groups build their internal communities and external networks just as they build the CoP with the public.

However, the low levels of analytical discussion on SRWs represent a latent contradiction, as García-Guerrero and Lewenstein (2020) have shown in the case of Mexico: Most practitioners and groups have neglected theory to focus almost entirely on practice. Discussions and collaborations are heavily based on empirical experience and tacit knowledge. It is still a challenge for the SRW community to reify its practice into a widely accepted set of concepts, with shared meanings, about what it does, how it does it, and why it does it in a certain way.

This lack of a fundamental shared conceptual framework is a critical barrier for reflection, discussion and, along with them, the maturation of the SRW community. Only by mutually engaging on essential principles for practice can SRW groups establish a much-needed process of reification. By publishing this article, we intend to work towards an initial reification, through reflective practice, that stimulates others to participate with us in further conversation (Nolen and Ward, 2008). We hope that
more practitioners will soon engage in the joint enterprise of discussing SRWs, helping them grow and earning well-deserved support for their activities.

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