The Tableau ST Project: Inspiring Francophone Teachers with Effective Science Practices

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The Social Sciences and Humanities Research Council (SSHRC) funded Tableau ST project involved two years of collaborative fieldwork with 19 francophone teachers and resulted in a repertoire of 53 effective science lessons and projects. To disseminate these resources, we designed an innovative, open access website (http://www.tableaust.ca) that provides ready-to-use lessons to elementary francophone teachers seeking to improve their teaching. For teachers, the website offers valuable and empowering tools to educate the science-literate citizens of the future. For scholars, the project, inspired by the heart-hands-head model, sheds new light on the definition of what constitutes effective science-teaching practices. The collaboration with the teachers has also led to identifying three new criteria for effective practices.

Le projet Tableau ST, relié au site http://www.tableaust.ca, est né d'une recherche participative qui a réuni chercheures et enseignants francophones pendant 2 ans, dans le but de disséminer plus d'une cinquantaine de pratiques gagnantes en sciences à l'élémentaire. Plusieurs critères contribuent à identifier les pratiques efficaces et parmi eux, l'apprentissage actif, le questionnement et le partage et la confrontation des preuves témoignent de la réflexivité des enseignants sur leurs pratiques en classe. Les critères gagnants agencés selon le modèle conceptuel Cœur-Mains-Tête pourront éventuellement servir à guider la pratique enseignante, mais aussi la formation des enseignants en didactique des sciences.

High-quality teaching of science and technology (ST) in elementary schools is indispensable to preparing students for middle-school and high-school science, and ultimately, to encouraging them to develop into scientifically literate citizens (Hopkins & McKeown, 2005). There is a need for effective methods that spark elementary students' interest in the sciences and provide them with a solid basis of fundamental scientific concepts and a critical understanding of the concrete contribution of science, technology, and society (Mueller, Tippins, & Bryan, 2012). In a fast-changing society, the teaching profession has become increasingly challenging, and many teachers are underprepared for science teaching. To provide students with engaging science education, it is crucial that teachers are motivated to improve their pedagogical skills (Fitzgerald & Smith, 2016). However, many dedicated Canadian teachers have been experiencing difficulties accessing ready-to-use, high quality resources in French. The Tableau ST project aims to offer teachers, by means of a francophone website, inspiring lesson ideas and concrete tools to support their science pedagogies. The project was initiated through a partnership between teachers and researchers (three first authors of this article). The teachers selected for the Tableau ST project were identified by their community as exemplary in engaging students in ST learning. Through extensive work with our teacher-colleagues, we have realized the potential of this project to provide teaching tools that ultimately help students become active and scientifically literate citizens (Lang, Drake, & Olson, 2006). Participating teachers brought into the project a repertoire of practices in ST based on their knowledge and experience, and were genuinely dedicated to sharing their best teaching practices.

Using a participatory research method, we selected locally-based, engaging teaching practices that fulfilled the quality-based criteria explained later. These practices were further refined and became the effective practices, the core material, of Tableau ST. The active teachers were essential collaborators/partners with the researchers. Together, we felt we could reach the main research objective: to understand quality ST teaching and to help teachers find and develop strategies to better engage their students. Currently, several websites, mostly in English, disseminate resources in ST to teaching practitioners. Among those websites, some provide practices and materials that have been developed by experts without necessarily having been tested in classrooms. Another limitation is accessibility, as some resources can be used by only registered or paying members. Open-access websites which share effective and authentic lessons or projects in science teaching (Van Zee & Roberts, 2006), written in French, and validated through a research-based project, are rare.

Furthermore, the heart-head-hands model, the framework for the set of effective science practices criteria developed throughout this study, will equip teachers and researchers with a concrete tool to improve science education. This model and the Tableau ST repertoire will also provide forward-thinking input for the reform efforts of governments and policymakers in re-conceptualizing science education. The results can also provide teacher educators with inspiring ideas and examples to deepen the discussion of effective practices with teacher candidates in order to develop strategies to promote scientific literacy in the classroom.

The first section of the paper presents the research program of the Tableau ST project, including its goal and questions about defining and disseminating effective practices in ST. We discuss high-quality teaching and learning in elementary science, and explain why teachers' professionalism and autonomy are important epistemological components in our research project. We provide a definition of effective practices and of the principles that underlie them. The methodology underpinning the work accomplished over five years, 2013 to 2018, is then presented. In the Results section, we discuss the heart-hands-head model as a framework for the criteria used to collect and analyze effective practices. In addition, we explain the design of the website, including the organization of the practices. We conclude by reflecting on some pedagogical implications, including a discussion of the results as well as the limitations of the study.

The Tableau ST Project

Meeting the needs of newly qualified teachers or even of those teachers who, after years in the profession, may still experience difficulties with science teaching, is a key goal of active researchers in science education (Couture, Dionne, Savoie-Zajc, & Auroussseau, 2015; Fitzgerald & Schneider, 2013). Despite the relative abundance of ST resources for elementary science teachers, there is a paucity of francophone resources validated by practice and research, and adapted to the Canadian provincial curricula (Couture et al., 2015). With this context in mind, in 2012 we submitted a proposal for funding to the Social Sciences and Humanities Research Council (SSHRC). The resulting funded project created an invaluable opportunity to work with two groups of passionate teachers who developed distinctive practices throughout their careers and were willing to share those practices virtually with other francophone teachers. The website: http://www.tableaust.ca shares those practices.

We used a participatory research method to understand the nature of effective teaching practices in ST. We worked collaboratively with teachers in two learning communities (LCs), providing a reflective space to discuss and deepen our shared understandings of successful ST practices. The collaborating teachers have developed their own ways to nurture a spirit of “organic and efficient” teaching in their classrooms (Mitchell & Sackney, 2016). Our goal was to establish a productive partnership with these practitioners and to work collaboratively to document, to refine and disseminate their successful ST practices (Fitzgerald & Schneider, 2013). Three research questions are at the core of this study: How can we collectively define what constitute effective lessons and projects in ST? How should the effective practices of participating teachers be selected, improved and collectively endorsed prior to dissemination? How can we present and widely disseminate on the web the effective lessons and projects selected?

Literature Review

We conducted a literature review to help define the key concepts explored in this section: a) the definition of quality science teaching; b) the expertise of teachers in determining quality teaching and; c) the definition of effective science teaching practice.

The Definition of Quality Science Teaching

As researchers, we are motivated to see more elementary classrooms offering quality teaching (Darling-Hammond, 2010; Fitzgerald & Smith, 2016). Many research findings point toward elementary teachers needing to adjust their ST practices (Appleton, 2006; Couture et al., 2015; Fitzgerald, Dawson, & Hackling, 2009; Fitzgerald & Schneider, 2013; Tytler, 2002; 2007). Other findings highlight the usefulness of making quality teaching and effective instructional strategies accessible to early career teachers or to teachers who are struggling with the science curriculum (Alsop, Bencze, & Pedretti, 2005; Cox, 2011; Nadirova & Burger, 2008).

Furthermore, research demonstrates that some aspects of traditional science teaching, for example answering questions from a textbook, might negatively affect students’ attitudes toward science (Reiss, 2004). Quality learning derives from quality science teaching that reflects present-day science practices, as well as changes in the nature of science and society, and have a more positive influence on students’ attitudes (Tytler, Symington, & Smith, 2011). Curriculum in elementary schools should better reflect the students’ real-world needs to prepare them to be responsible citizens. Many educators have been calling for improved primary-school teaching practices that take into account citizenship issues and engage students in comprehensive scientific and environmental projects (Aikenhead, 2003; 2006; Lang, Drake, & Olson, 2006). What is, precisely, effective science teaching? Establishing the professional authority of teachers is the first step toward answering this question.

The Expertise of Teachers in Determining Quality Teaching

Professionalism is characterized by the ability of teachers to make autonomous decisions and engage in reflexive practice. To foster a positive teaching and learning environment, teachers need to be valued and recognized as professionals. The epistemology of this study thus fully acknowledges teachers' capacity to assess and determine what an effective science lesson or project is. At the heart of this project is our deep valuing of teachers' professional commitment, insights, and practices (Cochran-Smith & Lytle, 2009). As Alsop, Bencze, and Pedretti (2005) point out, teaching is a balancing act; "on a daily basis teachers attempt to balance the cognitive, emotional and social needs of students; strategies for teaching, assessment, evaluation and classroom management etc.…" (p. 206). What sets exemplary practice apart may be the ability of some teachers to thrive in this chaotic environment and maintain the hope that they can make a difference in the lives of students.

Successful teachers act as leaders and guides who help develop students' awareness of socio-scientific issues (Mueller, Tippins, & Bryan, 2012). For example, oil-sand extraction has many interrelated consequences on the natural and human environment that teachers can help students explore and understand. In our research, the teachers we worked with were deeply committed to improving themselves through lifelong learning and research (Freiler et al., 2012). We therefore trusted their ability to accurately and effectively explain to the group why their chosen activities were successful in the classroom (Webb et al., 2004). To initiate and lead educational transformations, reflective teachers consciously engage with the value-base that underlies their work. By sharing effective practices, teachers take responsibility for leading their own and others' development (Cox, 2011).

The Definition of Effective Science Teaching Practice

Before defining effective science teaching practice, it is important to clarify what a complete lesson or project entails. For us, a science teaching practice is a complete lesson or project which includes clearly-stated learning objectives that can be accomplished in one or many teaching periods. At the onset of our research project, it was important to define quality science teaching. Education databases (e.g. ERIC) contain studies about high-quality teaching for a wide range of school subjects. These studies have used different concepts such as *best practices, exemplary practices*, or *effective practices*. Some studies correlate best practices with higher student performance or grades (Oliveira et al., 2013). Despite the benefits of those empirical projects, our approach was not to relate grade-based measures with successful practices, but to understand the authentic practices from the standpoint of the collaborating teachers.

In a search for a more comprehensive definition, effective teaching practices are not to be seen as a way to evaluate teachers' work, nor can they be used as standards for accountability measures. Successful practices should not be considered as homogenous processes but should rather be defined, according to Schön (1987), as insightful teaching practices which have been successful in the classroom. This definition of what constitutes an effective practice is based on internal processes such as teachers' self-reflection in and on practices within the real classroom (Schön). Alsop, Bencze, and Pedretti (2005), who worked with individual expert science teachers, introduced another key concept, exemplary practice, to represent teachers' successful science practices. For them, exemplary practice was the most accurate term within their casestudy method to embody the complexity and the uniqueness of those individual teachers' examples of effective practices.

In our study, the concept of effective teaching practices was adopted instead of best practices because we think that concept is a better translation of the French “pratiques gagnantes”. We also think the notion of “best” may not reflect the ongoing process of constantly striving to improve a lesson or a project. Improvements result from teachers' reflective practices designed to generate better learning outcomes, and from their dedication to respect learners' diversity and the specific contexts of their classrooms. Our initial source of inspiration for quality science teaching and learning was mainly the work of Australian researchers such as Fitzgerald (2012), Hackling and Prain (2005), and Tytler (2007). They used the concept of effective practices, defining it as those teaching practices which help students to learn (Fitzgerald et al., 2009). However, that definition is not completely satisfactory. Our study acknowledges teachers' capacity to determine what constitutes effective science teaching, and we wanted to explore and discover teachers' own definitions of a good science teaching practice. Through our participatory research design, we created a more comprehensive definition of an effective teaching practice that encompasses the teachers' practices, curricular expectations, and research findings (Couture et al., 2015).

Multiple criteria to define effective teaching in ST. The research project began with a set of criteria which partially defined effective science teaching practices (Fitzgerald, 2012; Hackling & Prain, 2005; Tytler, 2002; 2007). Using Australian documentation as well as references from European and American sources, the research team decided to expand the criteria of effective science teaching by conducting an in-depth literature review. An article by Couture et al. (2015) published in the *Recherches en Didactique des Sciences et des Technologies* journal provides the conceptual foundations for developing effective teaching practices for the Tableau ST project. The literature analysis resulted in the identification of six criteria to characterize effective science practice: (a) stimulating content to enhance students' interest using real-life examples; (b) an inquiry-based practice (Orange, 2012); (c) focus on concept building and conceptual understanding (Astolfi, Peterfalvi, & Vérin, 2006); (d) the presence of multimodality or the use of technology, visual representations and models etc., and of multiple representations (Hackling & Prain, 2005); (e) an assessment for learning and not of surface-learning; and (f) the teaching of science and technology using close linkages to the local community (Aikenhead, 2003). These criteria were sufficient to give us a base from which we could start working collaboratively with the participant teachers, but were incomplete in fully meeting the needs and definitions of teachers. The six criteria were expanded to nine when the work of collaborative teachers was added. The Results section elaborates on all of the criteria of effective science teaching as an outcome of the Tableau ST project.

Methodology

Our research methodology utilized a qualitative and interpretative perspective (Savoie Zajc, 2018) combined with a participatory approach within the LC setting (Dionne, Lemyre, & Savoie-Zajc, 2010). The aim of qualitative research is to better understand the world around us and to offer rich perspectives (Flick, 2007). In this section, we discuss the procedures related to the LC setting and present the methods for the analysis and identification of effective science teaching practices.

Participant Selection

Seven participant teachers from Ontario and ten from Quebec contributed to the creation of one LC in each province. Teachers were recruited on a voluntary basis, with slightly different recruitment practices in each province. In Ontario, science teachers[1] were identified by their school principal and were contacted individually. In Quebec, generalist teachers who were already involved in a science project with a pedagogical counsellor were recruited. In compliance with the ethics policies of our respective universities, no pressure or obligation was imposed on the teachers to join. Lessons and projects in Grades 4, 5, and 6, were considered.

Learning-Community Setting and Procedures

During the field work, using the LC setting, we jointly explored teacher practices in order to identify and characterize effective science teaching (Dionne & Couture, 2013; Dionne et al., 2010). In this study, working in a LC meant collaborating in a task-oriented, non-hierarchical setting where teachers and researchers engage in mutually enriching and beneficial professional development. Adopting an LC environment resulted in greater teacher professional satisfaction and a stronger individual, and collective, understanding and learning. The LC setting encouraged teachers to share their experiences and know-how, and simultaneously reinforced their professionalism and role in the research project (Cochran-Smith & Lytle, 2009; Dionne et al., 2010). We also noted from the onset that participating teachers were motivated to share with the researchers their views on effective teaching practices, as well as their pedagogical material and approaches. Over the span of the project, the LCs met for 10 full days in Ontario and seven days in Quebec. The agenda for those days included, but was not limited to, defining and identifying criteria of effective science teaching practices, sharing teaching strategies such as inquiry-based science, and discussing and collecting inspiring lessons and projects. At the onset of the field work, the criteria of effective science teaching were not given to the teachers. Teachers were encouraged to gradually formulate criteria as the project progressed. Throughout the journey, teachers articulated pedagogical considerations or tensions which were worthy of exploring within a larger educational context. Reflexivity and sharing of ideas were at the core of the process in the LCs, ensuring full collaboration between teachers and researchers.

Data Sources and Analysis

The sources of data to answer the research questions and gather all the components to build the website was the rich discussions at the group meetings, a log book kept individually by all teachers, as well as an analytical grid. The grid, based on the components of a lesson or project, was provided by the researchers in both LCs as a point of reference to facilitate the selection of effective practices. In the Ontario LC, a list of eight artifacts[2], email exchanges, and Google Drive were used to gather all the documents and to assemble the selected lessons or projects for the website. In the Quebec LC, the researchers first worked collectively to obtain a shared vision of effective science teaching. We then worked individually with each teacher to create a teaching narrative for every effective project. Artifacts for the website were excerpted from the narratives. A later collaboration with a teacher educator and two teachers from New-Brunswick (NB) resulted in the addition of three more effective practices. Iterative discussions and email exchanges guided the selection process for the NB practices. To optimise our shared collaborative work, we later engaged in a detailed process of revision to present each practice on a website. A thematic analysis was undertaken to review all the comments made by the teachers and researchers to construct a definition of effective science teaching and to delineate its associated criteria.

Results and Conceptual Framework

The results of the Tableau ST project are presented in this section. The first question aimed to deepen the understanding of what constitutes effective elementary science teaching practices and to define a shared set of criteria. The second question was directed at collectively agreeing upon and collecting effective practices based on participant teachers' best individual repertoires. The third question intended to create an innovative and resourceful website to showcase these quality projects.

The Heart-Hands-Head Model: A Conceptual Framework for Effective Teaching

We considered the definition of effective science teaching and its characteristics through the lens of a conceptual framework often used in education: the heart-hands-head model (Figure 1). Following an iterative process of data analysis, we concurred that the definition can be expressed as follows: Effective science teaching practice touches the heart, hands, and head of students. It induces interest among students and encourages their interactions with science-related daily activities (heart). It promotes active learning and the use of multiple representations (hands). Finally, effective teaching fosters inquiry-based science: questioning, debating, and developing students' concept building or conceptual understanding (head). This definition embraces an organic perspective; it captures a dedicated teaching repertoire that promotes constant student engagement, which research has demonstrated to be productive for learning in the sciences (Reiss, 2004).

The heart-hands-head model corresponds to the holistic approach of the Swiss pedagogue Johann Heinrich Pestalozzi (1746-1827), and is designed to encourage the development of well-balanced children who would grow to become responsible citizens. For Pestalozzi, empowering and ennobling every child was the only way to improve society and bring peace and security to the world. He sought to develop a complete theory of education that would promote happiness for humankind (Johann Heinrich Pestalozzi, n.d.). The model has been used in many

Figure 1. Heart, hands, and head model

educational fields, such as eco-literacy introduced by Orr (1992), and expanded by Sipos, Battisti, and Grimm (2008). In the field of environmental education, the model reflects the holistic nature of transformative experience. It relates the cognitive domain (head) to critical reflection, the affective domain (heart) to relational knowing, and the psychomotor domain (hands) to physical engagement. In science education, students must develop a high degree of competencies (hand) in order to learn efficiently. Meaningful learning then requires affective engagement (heart) with the manipulation of material resources (hands) to achieve cognitive mastery (head). Educators who nurture their students' heads, hearts, and hands genuinely help students improve their scientific literacy.

When our work with the teachers began, our goal was to understand their personal and collective vision about effective science teaching criteria. As a research result, both LCs identified innovative criteria to characterize effective teaching practices to be added to the original set from the literature. Three additional criteria emerged based on teachers' self-reflection about their teaching repertoire: active learning, questioning and sharing/exchanging ideas. In the end, nine criteria were identified to form the backbone of the Tableau ST website. These criteria are at the core of the definition and selection of successful lessons or projects.

The descriptions of the nine criteria of effective science teaching practices, based on the collective views of the LCs' members, and supported by scientific literature, are organized and presented based on the components of the heart-hands-head model. These descriptions demonstrate how effective practices engage the heart, hands, or head. Stimulating content and student engagement, links to community, or science-related daily activities are related to the affective domain (heart). The hands, or the sensorimotor dimension of the learning experience, encompass both active learning and the multimodality criteria. Lastly, the cognitive domain comprises many characteristics of science teaching linked to the brain such as inquiry-based science, questioning, exchanging of ideas, and assessment for learning.

The Affective Domain: The Heart

Two criteria of effective science teaching are directly related to the affective domain or the heart: stimulating content for student engagement, and community links or science-related daily activities.

Stimulating content for student engagement. Over the past millennia, human beings have always been curious and interested in exploring their environment. Young children have a natural curiosity, which is important to consider in effective practices. When sharing their visions of effective teaching practices, teachers emphasized the importance of encouraging student engagement by means of teaching with stimulating content. Most teachers in the Ontario LC reported a "wow" effect when students were showing great interest in a practice. Discussions in both LCs highlighted several times the need for science lessons or projects to be related to students' lives and interests, as well to learners' engagement in the science lesson. As Oliveira and colleagues (2013) have shown in their study of high-performance teaching in the United States, school science must be both fun and relevant to students' lives. This characteristic is clearly linked with the affective dimension in the learning process (Orr, 1992). Whether it involves the study of biodiversity in a forest near the school's ground or taking part in a space-discovery project to explore the characteristics of planets, students feel engaged in activities that are close to their everyday life and are more likely to demonstrate a genuine interest in learning.

Community links or science-related activities. In the joint work with the teachers, we noticed that selected lessons and projects sometimes involved resources or information shared with the local community or with science-related activities or events (Aikenhead, 2006). By grounding science teaching practices within the community, the learning process takes roots in the local environment and is linked to the affective domain: the forest around the students' houses, parents invited as experts, objects brought from home, etc. Although teachers in both communities accepted this characteristic as important, it was present in about half of the 53 shared lessons or projects. This criterion was also selected at the beginning of the project and aligns well with the documentation collected in the literature review on effective science teaching practices (Couture et al., 2015). For example, the use of school grounds as a means to educate students about environmental issues constitutes a resource, which in our experience is too often under-utilized by teachers. More common were projects or activities that asked parents to collaborate in the collection of recyclable materials for the purpose of making models. Using recycled material or items may help students to understand the importance of recuperation and re-utilization, as well as the negative effects of overconsumption. Furthermore, inviting a parent who works in the scientific field, for example in a water-treatment plant or in a hospital, could help to create greater awareness and broaden perspectives in ST, while also promoting sensitivity to the local environment and science-related daily activities. All in all, linking science and scientists with social issues and school science may help to bring a humanistic perspective to effective science teaching (Aikenhead, 2006).

The idea of community participation in the classroom is at the core of what Mueller, Tippins, and Bryan (2012) called citizen science: as when students genuinely want to become involved citizens to solve local problems such as water or air quality and threats to biodiversity. Maximizing the participation of community human resources in the classroom, as well as working in and with the community, may contribute to developing empathy and to building a common vision for environmental solutions to improve the local environment.

The Sensorimotor Domain: The Hands

Two criteria of effective science teaching, active learning, as well as multimodality and multimodal representations, encompass the hands component of the model.

Active learning. Action without reflection may be unproductive, often resulting in wasted time. On the contrary, active learning is defined as an activity that involves the manipulation of materials, which enables students to reflect on what they are doing (Bonwell & Eison, 1991). This criterion truly engages students in the task or activity they are conducting; it is a process of developing competencies by manipulating materials, taking and understanding measurements, engaging with data, etc. The learner's activity is multileveled, involving muscles, movements, and actions while at the same time engaging the brain, with all levels being involved synergistically through the learning process. Hands-on activities need to be well-guided by teachers in order for the students to comprehend the underlying scientific principles and build their conceptual understanding. This rather innovative characteristic was proposed by our participant teachers in both LCs. At the onset of the project, active learning was not identified as a separate characteristic of effective science teaching but was rather linked, in the scientific documentation, to inquiry-based science (Hackling & Prain, 2005; Fitzgerald, 2012). Active learning enables students to carry on conceptual scaffolding and is also intimately linked to concept building (Bonwell & Eison, 1991).

Multimodal teaching and multiple representations. The role of language is central for communicating ideas and findings among scientists, but communication also involves the use of hands to produce modes and systems of meaning-making such as multimodal representations. Figures, graphs, diagrams, mathematical equations, actions, 3-D models, technological applications, visual communication, etc. are multimodal representations which correspond to essential components of effective teaching practices. Whereas multimodality is the process used to foster meaning-making using a multiplicity of representations, multiple-representations research examines how students make sense of a representation using multiple modes (Klein & Kirkpatrick, 2010; Tang, Delgado, & Moje, 2014). Known as an important feature of successful teaching and adopted in our initial framework, the multimodal nature of science teaching, or multimodality, requires teachers to use several types of instructional artifacts such as written material, oral or audio presentations, graphics, visuals, etc. (Lopes et al., 2014). In the learning process, multiple representations play an important role in mediating the meanings learners produce with their hands as well as with their heads (Jewitt, Kress, Ogborn, & Tsatsarelis, 2001). The types of models or prototypes built may range from simple hand-made models to complex technological designs. Thus, students can demonstrate their knowledge in a format which is different from conventional pencil and paper and mobilize other competencies such as building or role-playing. In the effective classroom, exemplified by practices selected in our research project, multiple representations are multiform: sometimes artistic and creative, and range from students building an insect model to constructing a solar system.

The Cognitive Domain: The Head

Under the umbrella of the cognitive domain, we find, by far, the largest number of effective science teaching criteria: inquiry-based science, questioning, sharing and exchanging of ideas, concept-building or conceptual understanding, and assessment for learning.

Inquiry-based science. Inquiry-based science is a process and a building block in science and technology teaching. It is a form of scientific investigation in which students are invited to identify questions and develop their own solutions (Orange, 2012). Generally, inquiry-based science involves problem-based learning and aims to engage in authentic sense-making and knowledge-constructing processes (Emmer, 2018). This effective characteristic is omnipresent in many studies on efficient teaching in science education, as well as in several science curricula. Any type of inquiry should involve a thinking process, which links the inquiry with rich, transferable concepts (Orange, 2012). Thinking can range on a continuum from very simple to very complex. For example, one type of inquiry is observation, such as asking students to observe the parts of an insect in order to represent it in a model. A more sophisticated type of inquiry is an experiment about chemical versus physical changes (e.g. testing the effect of vinegar on an eggshell), building a model (e.g. finding the best way to represent a human skeleton), or even more complex, such as resolving a technological problem (e.g. making a mechanical car using elastic bands). These examples demonstrate that the process of inquiry-based science can be seen as both active and cerebral, allowing the students to link hands to head and to observe, question, and solve a problem. As recommended by Orange (2012), asking students to get involved and be successful in the multiple processes of inquiry necessitates giving them access to a broad knowledge base with multiple documentation sources.

Questioning. Our results indicate that questioning is the foundation of all teaching in ST. Unfortunately, "questioning in the American classroom is among the weakest elements of instruction" (Windschitl, Thompson, Braaten, & Stroupe, 2012, p. 881). Members of the Quebec LC observed that questioning activates student interest and linked this criterion with student engagement (heart). In the selected practices, students are encouraged to reflect on such questions as: How do plants grow? How is the skeletal system organised? What are the characteristics of the planets which make up our solar system? How can a tower be strengthened? Good questions come from deep thinking processes and lend themselves to a why and how form of inquiry that requires explanation. Searching for answers or asking new questions contributes to developing, as well as reinforcing scientific attitudes and thinking processes are thus essential skills which need to be developed and promoted among students (Orange, 2005; 2012). Questioning relies on students' mental ability to inquire and to come up with possible solutions. Although the importance of questioning was mentioned in the provincial curricula and research articles (e.g. Orange, 2012), it did not appear as a specific and separate characteristic in the initial set of effective science teaching characteristics. Teachers in both LCs argued that questioning needed to be singled out as an effective science teaching criterion and be mindfully integrated into science classroom.

Sharing and exchanging of ideas. The head or the cognitive domain is linked to the transformational learning experience offered through expanded perception (Orr, 1992). Sharing and exchanging ideas belongs to the cognitive domain and to 21st century skills involving teamwork, communication, and collaboration to develop innovative ideas (Trilling & Fadel, 2009). Grouping students in small teams provides opportunities for new and shared ideas to emerge, and also to exchange what they have learned in order to identify similarities and differences. Furthermore, exploring new ideas in small groups is part of problem-solving, or what Orange (2005) called problematization. The vast majority of lessons or projects selected for the Tableau ST involved sharing and exchanging ideas among students. In some examples, teachers recommend facilitating the exchange by identifying specific roles within the team. In other examples, teachers viewed themselves as facilitators in order to encourage the exchange of ideas and/or to debate the solutions proposed by the students in the science classroom. The sharing and exchanging of ideas were not present in the initial set of criteria to define effective science teaching, although that criterion was highlighted in some studies on problematization or problem-solving (Orange, 2005; 2012). The importance of this criterion was stressed by teachers in both LCs as a separate and unique head characteristic, for its power to help learners meet the learning outcomes.

Concept-building or conceptual understanding. This criterion corresponds to the scaffolding process and mediation involved in understanding a scientific concept or phenomenon. Concept-building was an important starting point for discussions in the LCs in order to take into account curriculum requirements. Concept-building or conceptual understanding in science is the ultimate goal of most science practices (Lang et al., 2006; Windschitl et al., 2012). From the students' perspective, it involves the use of complex and specialized terminology to provide an explanation. For example, the term "force" is useful to explain the building of a bridge; it implies understanding the different internal forces acting upon its structure, such as compression and tension. The concept of roots[3] in plants is another example which may elicit and facilitate more sophisticated representations, and terms such as radicles, superficial roots, bareroots, and rhizomes. This use of specialized vocabulary will develop after the students have been able to first describe a scientific phenomenon in their own words. Conceptual understanding, one of the criteria described in our initial conceptual framework, is present in many studies on effective teaching (Couture et al., 2015; Fitzgerald et al., 2009; Hackling & Prain, 2005). It also represented an important characteristic for all teachers participating in this study.

Assessment for learning. Assessment for learning refers to the evaluative stance which enables students to demonstrate their knowledge and, in doing so, to create new knowledge or to consolidate what they already know. It plays an important role in many effective teaching practices (Cox, 2011). It may allow the teacher to assess high-order thinking skills, which are important for students' future studies or careers (Schulz & FitzPatrick, 2016). This evaluative stance is contrary to the assessment of learning, or surface learning that may be present when teachers ask students to recall information for a test (Hattie, 2009). Along this vein, in the Tableau ST project, the practice of Espace création (creative space) involves the use of maker-space in the classroom. At the end of a learning module, students are asked to use their creativity and imagination to foster their concrete understanding of important scientific concepts. In the unit about structures and forces in the Espace création for instance, students are asked to quickly build a bridge. However, it is not the sturdiness of the structure that is at the core of their activity but rather the explanation they will provide regarding the bridge's capacity to support a specific weight. This criterion was initially selected in the framework for effective science teaching and is frequently relevant in the practices of the Tableau ST website (Couture et al., 2015; Hackling & Prain, 2005).

The Tableau ST Website: A Collection of Effective Science Teaching Lessons and Projects

To answer the third research question, after two additional years of formatting teaching practices, the Tableau ST website provides an inventory of 53 effective lessons and projects, from the nineteen teachers who were willing to help their fellow colleagues with their science teaching. Thirty-eight lessons and projects were shared from the Ontario community and twelve from Quebec. Three additional projects were added, thanks to the collaboration of two NB teachers. All the activities selected to build the website are summarized in Table 1.

The projects are organized by grade level and by domains: Living Systems, Structures and Mechanisms, Matter and Energy, Earth and Space, and Interdomaines (an interdisciplinary domain), which includes lessons linked to more than one domain (Ministère de l'Éducation de l'Ontario [MEO], 2007). Grade 6 has the most projects, 23, followed by 17 projects for Grade 5, and 13 projects for Grade 4. Fifteen lessons or projects are related to Structures and

Table 1.

Inventory of Effective Teaching Practices in the Tableau ST by Grade and Domain

Grade level/ units	Interdisciplinary domain	Life systems	Structures and mechanisms	Matter and energy	Earth and space	Total
Grade 4	0	4	3	4	2	13
Grade 5	4	2	7	2	2	17
Grade 6	2	4	5	6	6	23
Total	6	10	15	12	10	53

Mechanisms. Projects from Quebec are popular in this field, given the Défi Apprenti Génie (Invention Challenge)[4], an annual competition held to promote the integration of creativity and technology innovations in Quebec classrooms. The Matter and Energy domain includes 12 lessons and projects, with many concepts related to electricity. This is followed by 10 projects and lessons in each of the domains of Living Systems, and Earth and Space. Many projects in Grade 6 are about space exploration, perhaps due to the frequent coverage of space issues in the media.

A key goal of the research was to share these effective science teaching practices in a rigorous and inspiring manner. All selected lessons and projects have been available, open access for all francophone teachers from Canada or elsewhere in the world since Fall of 2017 on the website described below. The design of the website is derived from Mendeleev's periodical table of elements (Figure 2), the intrinsically scientific character being an asset. Inspired by the idea of an efficient and attractive arrangement, we believe that this famous design renders effective lessons and projects conveniently accessible.

In the website, selected lessons and projects are grouped according to their curricular domains. The domains are displayed on the abscissa axis. Grades 4 to 6 correspond to the ordinate axis. All the lessons and projects were gathered from the teachers' repertoires and integrated into an artifact structure: an atomic-shape model (Figure 3) that allows easy access to the full range of pedagogically informed resources. The model is made up of eight types of artifacts: (a) activity description, (b) photos of student projects, (c) worksheets, (d) assessment, (e) internet links, (f) list of effective practice criteria, (g) scientific capsule, and (h) credits and references. In all lessons or projects these three artifacts are present: the description, the specific set of effective practice criteria, as well as the credits and references.

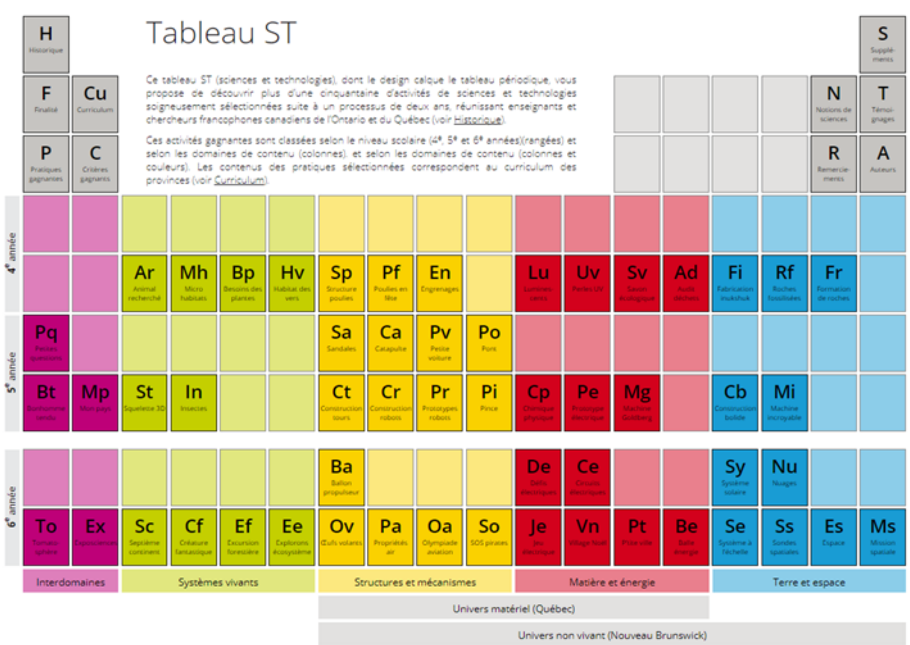

Figure 2. Design of the Tableau ST website.

Figure 3. Atom-shaped organisation of effective science teaching practices using artifacts.

Each practice is presented with a complete description or lesson plan, followed by photos of students' work and lesson handouts (for the students and/or the teacher). In many lessons or projects, the assessment method is explained in detail, and, if required, assessment documents or matrices are included. Also made available, for specific lessons or projects, is a scientific capsule which describes and explains the main scientific concepts relevant to the learning activity. In some cases, a list of Internet links used in the activity, or as a complement, is also provided. Each lesson or project includes a diagram of the relevant set of effective science teaching criteria. Each practice has several characteristics; in general, at least five out of the nine criteria characterized each lesson or project. Finally, the names of the teachers who shared the practices, as well as references, are provided.

Discussion

Our intention was to define effective teaching practices in a collective manner, which made sense for teachers and researchers alike, in both provinces. Overall, the results reflect the teachers' understanding of effective science teaching from the perspectives of their classroom practices. Our analysis has enabled us to deepen and enrich our understanding of effective science teaching criteria. Via the framework and the reflection undertaken with the teachers, it was possible to identify three new criteria in addition to the six criteria from the scientific literature: active learning, questioning, and sharing and exchanging ideas. The definition of effective science teaching and the arrangement of criteria using the heart-hands-head model can be understood in terms of the interrelated dimensions of an ecological system. The phenomenon of scientific literacy is ecological; literacy learning is not a simple transfer of knowledge and skills from teacher to student. It grows out of multiple interactions between people, curriculum material, and activities (Syverson, 2008). To give a few examples of this interconnectedness, inquiry-based science requires competencies from the hands-model component. When teachers assess learning outcomes, they show care and concern for their students' knowledge and touch their hearts. As a result, students develop a more profound acceptance of their own strengths and weaknesses. When the arrangement of effective science teaching criteria is examined globally, the data shows that the head model component is over-represented, with twice as many criteria than the other components. This predominance reflects the nature of science as a human endeavour, as well as the nature of schooling and the learning processes, which rely on the human mind (Aikenhead, 2006).

Another interesting result is the link the Quebec LC made between the two criteria of stimulating content and questioning. That link may be understood as a curriculum-effect, as the Quebec science curriculum is competency-oriented and greatly emphasizes questioning by the students (Ministère de l'Éducation, du Loisir et du Sport [MÉLS], 2001). In terms of the hierarchical organisation of the criteria, our analysis suggests that the criteria may function on three levels: (a) students' interest, (b) scientific processes and, (c) learning outcomes. At first, the heart and the head must be solicited to stimulate students' interest. Stimulant content (heart) may create even more stimulation when arising from community links or science-related activities (heart) and is then combined with questioning (head). The second level includes the scientific processes involving active learning (hands), inquiry-based science (head), sharing and exchanging ideas (head), and multiple representations (hands). The third level is related to the learning outcomes with concept-building (head) and assessment for learning (head). Uncovering effective teaching criteria allowed us to identify and select those lessons and projects worthy of dissemination to support early career francophone teachers.

Another important contribution of the Tableau ST project is the website. We shared 53 practices contributed by two groups of elementary teachers from Ontario and Quebec working in LC settings, as well as three practices from two NB teachers. This was made possible thanks to the joint efforts of several actors, mostly the devoted teachers who collaborated with the researchers because they believed in the value and relevance of this project. Although these inspirational effective science teaching practices are a part of their everyday work, the teachers took on a great deal of extra work in order to help support other teachers (Cox, 2011).

Limitations of the Study

Although we do not intend to propose the Tableau ST as a panacea, nor imply that we satisfy all the intricate requirements of the science curricula from grades four to six, we believe that the Tableau ST, with its focus on effective science teaching practices, can provide francophone teachers from Canada and elsewhere with exemplary projects to supplement their classroom activities and lesson plans, whilst at the same time improving science teaching for the French-Canadian primary-junior classrooms. The website aims to help meet the science-related needs of struggling teachers by disseminating authentic science projects (Fitzgerald & Schneider, 2013). Very few websites with authentic exemplary practices promote the minority language, as well as l'éducation en français. French is spoken in Quebec, in other Canadian provinces, and in other French-speaking countries around the world. Undoubtedly, in the Tableau ST project, the choices of lessons and learning activities are somewhat context-dependent, a product of the communities we worked with. In making our choices, we could not ignore the influence of the provincial science curricula at the elementary level, as well as the sociocultural contexts. Under other circumstances, the criteria could have been interpreted or organized differently. During the creation of the website, there was no formal teacher consultation along the way, outside of the LCs. The website was briefly tested by a small group of pre-service teachers in Ontario at the beginning of 2017. In our ongoing effort to improve this resource and make adjustments, we would like to receive feedback from website users. Our work and the website cannot guarantee that teaching in science and technology education will improve. However, despite the contextualized nature of the Tableau ST website and of the research itself, francophone teachers from Canada and elsewhere may feel supported by the website and find tools to work more effectively in the science classroom (Darling-Hammond, 2010).

Implications and Future Directions

To the best of our knowledge, the Tableau ST website is unique for two main reasons. First, it relies on successful teachers' practices coming from their shared repertoire. Second, the research process itself relied on the solid partnership and true collaboration between researchers and practitioners in order to identify effective science teaching practices. At the beginning of the project, some of the teachers were not entirely at ease with asserting that their practices were effective. However, the researchers were engaged in nurturing the LCs in order for the teachers to feel comfortable and to experience a fulfilling and empowering professional development experience (Dionne & Couture, 2010; 2013; Dionne et al., 2010; 2015). With perseverance, continued support, enriched discussions in the LC meetings, and opportunities to reflect on and improve what the teachers already did in their classes, we were able to collectively select effective science lessons and projects.

In Ontario, pre-service teachers need to enroll in only one three-credit course in science education. In Quebec, two three-credit courses over a four-year program are often required. The small number of credits devoted to science education preparation may greatly restrict teachers' training in this field. Knowing that weak science knowledge may affect teachers during the first years of their career, the Tableau ST could therefore be adopted to provide targeted instruction in ST to new francophone teachers (Fitzgerald, 2012). In some teacher programs in Ontario, nearly 50% of the teacher candidates may be immigrants. This teacher-candidate population may struggle even more when they are required to teach the sciences at the junior level (Brown, Dashwood, Lawrence, & Burton, 2010). Some researchers pointed out the necessity to provide enough support, encourage positive attitudes, develop greater competencies, and increase the willingness to teach science, especially for new teachers (Appleton, 2006; Dionne & Couture, 2010; Enoch & Riggs, 1990; Reiss, 2004). Some research recommends presenting high-leverage practices, such as the practices displayed in the Tableau ST, during teacher preparation and induction to support new teachers across various learning-to-teach contexts (Windschitl et al., 2012). Furthermore, teacher educators involved in francophone Bachelor of Education programs might be interested in using the Tableau ST to demonstrate, illustrate, and encourage discussions concerning effective science teaching practices. Pre-service teachers can draw on the inspiring framework of the heart-hands-head model before they are immersed in real classroom situations and use it to frame their curriculum materials (Schwartz et al., 2008). Ongoing discussions should be encouraged with teacher candidates around the issues of the implementation or adaptation of these practices in real classroom contexts, as well as in the creation of authentic learning environments. With regards to teachers' professional development, effective science teaching practices that use the criteria model could be shared with school councils and ministries of education to inspire teachers, and to improve science teaching. The Tableau ST may be a source of inspiration to guide professional development in science education and/or provide an effective tool to create innovative professional development programs for science teaching. The website and the criteria model can be used by individual teachers to improve or develop their own effective science teaching modules in a manner that attempts to address each of the interrelated developmental dimensions such as community links, active learning, and exchanging of ideas. They can be used by French immersion programs, as well as for home schooling. We believe that this resource, if disseminated and utilized by Grades 4 to 6 francophone teachers, may help to support and improve science teaching practices. Improved teaching in elementary science will help students become scientifically literate, prepare students for middle and high-school science, encourage the pursuit of careers in science and technology, and encourage active engagement in society to create a better future.

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Notes

1 Four teachers in the Ontario LC were science specialists from grade 1-6. Two teachers taught science as well as other subjects to 2-3 groups of students from the same grade. One teacher taught all subjects to a Grade-4 classroom.
2 Eight different pieces or artifacts were used in a differentiated pattern to characterize each selected effective teaching practices: (i) activity description, (ii) photos of student projects, (iii) worksheets, (iv) assessment, (v) Internet links, (vi) list of effective practice characteristics, (vii) scientific capsule and (viii) credits and references.
3 https://fr.wikipedia.org/wiki/Racine_(botanique)#DiffC3.A9rentes_formes_de_racines
4 Technoscience network (*Réseau technoscience*), Province of Québec.

Liliane Dionne is an Associate Professor in the Faculty of Education at the University of Ottawa. She specializes in science and technology education and participative and qualitative research methods applied to education. Principal researcher of the project and designer of the SSHRC-funded TableauST.ca, Professor Dionne led all phases of the project with co-researchers and teachers. She worked in the field with the Ontario learning community to characterize and identify nearly forty effective practices in science that are shared on the website. Professor Dionne has been a researcher on four SSHRC-funded projects, two of which were as head researcher. Her scholarly publications on science education and learning communities are known both here and internationally.

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Professor Emeritus at the Université du Québec en Outaouais (UQO), *Lorraine Savoie-Zajc* is recognized for her expertise in educational research methods and with learning communities. She participated in the Tableau ST project by contributing more specifically as a senior project advisor, and in fieldwork with the learning community in Ontario. Author of numerous scholarly books and articles on the role of learning communities, action research and change in education, Professor Savoie-Zajc is internationally recognized for her work.

Natascia Petringa is a second-year PhD Candidate at the University of Ottawa, currently studying under the thesis supervision of Prof Liliane Dionne. She has been a science teacher for 20+ years in Europe and shares a special interest in multimodal teaching practices in science, especially for English Language Learners (ELLs). Having been exposed to the Tableau ST project only two years ago, Natascia will assist the team of researchers in analyzing the use of the website projects and collecting feedback.