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LEARNING

Reading between the lines: The effect of contextual factors on student motivation throughout an open inquiry process

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Abstract

Inquiry provides opportunities to engage students in authentic science. Although inquiry's underlying principles can motivate students to learn, the challenges that students encounter may hamper their motivation. Thus, the teacher's role in providing motivational support is crucial. This research examines how the interplay among the inquiry's characteristics, the challenges encountered by students, and the motivational support provided by the teacher affects students' expression of motivation throughout an online inquiry process. The messages of both the teacher and the students were examined using self-determination theory (SDT). The results indicate that the students did not automatically embrace the autonomous characteristic of open inquiry. Their expressions of motivation were dynamic, affected by the challenges that they encountered. In contrast, the teacher maintained high levels of autonomy and competence and intertwined these components in a strategy that we term *guided autonomy*. The teacher and students expressed high-order expressions of affect. In addition, we found a positive correlation between the teacher's motivational support and the students' expressions of motivation. The results indicate that SDT can provide a powerful framework for understanding students' unfolding motivation throughout a challenging educational process and for guiding teachers' efforts in supporting the motivation of their students in an online environment.

KEYWORDS

inquiry, motivation, online learning, self-determination theory

1 | INTRODUCTION

Scientific inquiry provides an opportunity for students to engage in authentic science and to experience the cognitive, epistemic, and social processes applied by scientists (e.g., Lee & Butler Songer, 2003; Wagh, Cook-Whitt, & Wilensky,

2007; Windschitl, Thompson, & Braaten, 2008). Among the underlying principles of scientific inquiry are autonomous and self-regulated learning, freedom of choice, alignment with personal interests, and authenticity (Blumenfeld, Kempler, & Krajcik, 2006). These principles are central to the capability of the inquiry process to engage students in thinking deeply about the content and in constructing an understanding that entails the integration and application of the key ideas of academic disciplines (Blumenfeld et al., 2006). These principles also play a crucial role in the capability of inquiry-based learning to motivate students to engage in the excitement of science (Blumenfeld et al., 1991, 2006; Sturm & Bogner, 2008; Tuan, Chin, Tsai, & Cheng, 2005).

Inquiry-based learning also provides new challenges concerning student motivation. Aligned with constructivist theories, inquiry changes the features of traditional learning environments, requiring the learner to reconstruct meaning (Veermans & Järvelä, 2004). In addition, the inquiry process changes the cognitive divisions of labor and shifts the responsibility for learning and regulative efforts from teachers to students (Veermans & Järvelä, 2004). This challenging approach to learning requires students to be motivated, initially as a means to encourage their participation in the inquiry process. In addition, students must be able to sustain their motivation throughout the process until they complete their knowledge construction (Palmer, 2005). Thus, motivation serves as both a prerequisite and a corequisite for learning, engagement, and improved outcomes (Palmer, 2005).

Indeed, research suggests that providing students with an authentic and problem-based experience does not automatically guarantee student engagement (Belland, Kim, & Hannafin, 2013). For example, Edelson, Gordon, and Pea (1999) demonstrated that one of the challenges associated with students' ability to conduct systematic inquiry activities in high school science is sustaining students' motivation for inquiry. Veermans and Järvelä (2004) demonstrated that students' engagement and motivational profile throughout the inquiry process were associated with achievement goals and coping strategies. Since research on the affective aspects of learning emphasizes the central role of motivation and emotions in academic cognition (Fortus, 2014; González, Fernández, & Paoloni, 2016; Koballa & Glynn, 2007; Pintrich, 2003), it is crucial to promote and sustain student motivation throughout the inquiry process.

Providing students with cognitive and motivational support and with instruction to invest their efforts in learning is crucial to ensure their involvement in the inquiry process (Belland et al., 2013; Palmer, 2005). Research on scientific inquiry highlights the pivotal role of instruction, guidance, and scaffolding within the inquiry process to facilitate students' learning and outcomes (Crawford, 2000, 2012; Furtak, Seidel, Iverson, & Briggs, 2012; Lazonder & Harmsen, 2016; Minner, Levy, & Century, 2010; Rönnebeck, Bernholt, & Ropohl, 2016). Research also highlights the crucial role that teachers play in supporting their students' motivation throughout the inquiry process (Crawford, 2007; Veermans & Järvelä, 2004). For teachers to support their students, educators must (a) anticipate the difficulties of students during the inquiry process and (b) deliberately target and trigger student motivation (Blumenfeld et al., 2006). Educational interventions can influence student motivation when they are based on clear theoretical foundations or rationales, such as establishing the task value, providing social interaction, promoting mastery goals, regulating emotions, and providing expectations for success and autonomy (Belland et al., 2013; Wigfield & Wentzel, 2007). The tenets of self-determination theory (SDT) (Deci & Ryan, 2000), including autonomy, competence, and relatedness, have often been cited as determinants of student motivation in an inquiry process (e.g., Belland et al., 2013; Blumenfeld et al., 2006; Scogin & Stuessy, 2015; Sloan, 2015).

A literature review reveals that only a few studies have addressed the emotional and motivational aspects of the inquiry process (Fortus, 2014). Furthermore, studies that have examined the motivational aspect of students' engagement in inquiry within a technological environment are scarce (Belland et al., 2013). Examining these aspects is important because of their effect on students' engagement and learning outcomes. In addition, understanding the temporal dynamics of student motivation is the basis for the design of effective interventions (Pintrich, 2003). Therefore, this study aims to examine how the interplay among the inquiry's characteristics, the challenges encountered by the students during the process, and the teacher's motivational support impacts students' expression of motivation throughout an inquiry process in an online asynchronous forum. The specific goals of this study are as follows: (a) to identify patterns and shifts in students' unfolding temporal motivation throughout an inquiry process, (b) to identify patterns and shifts in the way the teacher supports the students' motivation during the inquiry process, and (c) to examine the

interaction between the students' expressions of motivation and the motivational support provided by the teacher during the inquiry process.

The context for this study was an open inquiry process in a blended learning environment that included both face-to-face and online instruction. The online instruction occurred through a forum, a specific type of computer-supported collaborative learning environment in which students work and collaborate over the Internet without the constraints of time or space (Janssen, Erkens, Kirschner, & Kanselaar, 2012; Stahl, Koschmann, & Suthers, 2006). Online forums have been shown to promote interactions among participants, which is an essential component of successful learning (Woo & Reeves, 2007). These forums also support and improve highly effective types of learner-to-learner interactions. These interactions enable students to exchange information, contribute to discussions, and provide opportunities for students to acquire and examine alternative perspectives easily (Dillenbourg, Järvelä, & Fischer, 2009; Woo & Reeves, 2007). The asynchronous dialogues and delayed response time that occur in an online forum enable participants to think before they speak, reflect upon their communication, and monitor the discourse (Clark, Weinberger, Jucks, Spitulnik, & Wallace, 2003; Cohen & Scardamalia, 1998; Veerman, Andriessen, & Kanselaar, 2000; Zion, 2008; Zion, Michalsky, & Mevarech, 2005). Using SDT (Deci & Ryan, 2000) as a framework, we analyzed the correspondence of both the students and the teacher in the online forum that accompanied the inquiry process and searched for expressions of motivation throughout a yearlong inquiry process.

2 | THEORETICAL FRAMEWORK

In this section, we first discuss our theoretical foundations to understand students' learning. These foundations include the conceptualization of inquiry and SDT constructs that can explain students' engagement and motivation. Then, we discuss the implications of these foundations for instruction in general and for online environments in particular.

2.1 | Scientific inquiry

Scientific inquiry refers to "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (National Research Council [NRC], 2000, p. 23). Inquiry-based learning is grounded in constructivist theories (Piaget, 1971; Vygotsky, 1978). According to this view, students do not passively absorb information; to attain meaningful learning, students must actively create and modify knowledge structures. For decades, engaging students in scientific inquiry has involved the following academic cognitive goals: facilitating students' understanding of science concepts, developing students' abilities *to perform* scientific inquiry, and promoting students' understanding *of* scientific inquiry and the nature of science (Crawford, 2007). Hence, scientific inquiry has been viewed as both a means to develop scientific content knowledge and an outcome, an understanding of scientific inquiry itself (Abd-El-Khalick et al., 2004; Anderson, 2002; NRC, 2000).

Following the publication of *The National Science Education Standards* (National Academy of Science, 1995), teaching science as a process of inquiry has become a dominant paradigm in the United States (Osborne, 2014). Osborne (2014) describes several problems that were associated with this approach: (a) confusion over the goal of *science*, i.e., to discover new knowledge, vs. the goal of *learning science*, i.e., to build an understanding of existing ideas; and (b) confusion over the goals of *engaging in inquiry*, i.e., an engagement that develops a deeper understanding of the nature of scientific inquiry, vs. the goals of *engaging in laboratory work*, i.e., an engagement in illustrations or verifications of the phenomenological accounts of nature. In many cases, inquiry became primarily associated with "hands-on" science, neglecting critical reasoning, the analysis of evidence, and the construction and evaluation of arguments and explanations (NRC, 2012b). An additional trend involved treating scientific methodology independently of content, resulting in the teaching of a generic "scientific method," a linear sequence of steps, emphasizing experimental investigations. Students were then instructed to apply the scientific method in a superficial or scripted way (NRC, 2012b). In an effort to overcome these problems, the *Framework for K-[12 Science Education* (NRC, 2012a) advocated a teaching approach through which disciplinary core ideas and crosscutting concepts are integrated with scientific practices. In accordance

with this approach, inquiry serves as a means to engage students in the ideas, concepts, processes and practices of authentic science. By engaging in inquiry, students can develop "a grasp of practice," an understanding of the epistemic basis of science and its key reasoning patterns (Ford, 2008a, 2008b). According to Crawford (2014),

> *teaching science as inquiry involves engaging students in using critical thinking skills, which includes asking questions, designing and carrying out investigations, interpreting data as evidence, creating arguments, building models, and communicating findings in the pursuit of deepening their understanding by using logic and evidence about the natural world. (p. 515)*

Scientific inquiry in classrooms takes various forms. For example, students' inquiries can be designed to support students in constructing scientific explanations and argumentation by engaging them in generating evidence-based claims and articulating their reasoning (Berland & Reiser, 2009; Reiser, Berland, & Kenyon, 2012). Inquiry can also be designed to engage students in scientific reasoning (Chinn & Malhotra, 2002). Model-based inquiry, in which students engage in iterative cycles of model construction, deployment, and evaluation, has been shown to support students in the co-construction of inquiry, modeling practice, and scientific knowledge (Lehrer & Schauble, 2012; Lehrer, Schauble, & Lucas, 2008; Manz, 2012), and inquiry allows students to acquire a grasp of scientific practice by constructing and mainly providing a critique of claims (Ford, 2008b, 2010). Inquiry encompasses a broad spectrum of approaches, ranging from teacher-directed to student-directed approaches (e.g., Blanchard et al., 2010; Buck, Bretz, & Towns, 2008; Bunterm et al., 2014; Fang et al., 2016; Sadeh & Zion, 2009). Schwab (1962) and, subsequently, Herron (1971) identified a range of "openness" in the inquiry process based on both the degree of students' involvement and the degree of teachers' instructional interventions: The more responsibility that teachers assume, the more guided the inquiry is; the more responsibility that students assume for posing and responding to questions, designing investigations, and extracting and communicating their learning, the more "open" the inquiry is (NRC, 2000). In *open inquiry*, students are active decision makers throughout every stage of the open inquiry process: Students pose a self-directed question, they determine what constitutes evidence and collect it, they formulate explanations after summarizing the evidence, they independently examine other resources and form the links to explanations, and they form reasonable and logical arguments to communicate explanations (NRC, 2000).

Research demonstrates that inquiry-based instruction can promote student growth in both scientific skills and content knowledge (e.g., Geier et al., 2008; Marshall, Smart, & Alston, 2017; Wilson, Taylor, Kowalski, & Carlson, 2010). The extent of these gains is generally associated with the design of the inquiry process in the classroom as well as the amount and quality of the scaffolding and guidance used to facilitate students' learning (Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Sweller, & Clark, 2006; Lazonder & Harmsen, 2016; Wilson et al., 2010).

2.2 | Affective and motivational aspects of inquiry

Motivation and emotions are considered central to cognitive engagement (Fortus, 2014; González et al., 2016). Presently, various motivational theories are often used in science education to examine the affective aspects of learning (Fortus, 2014; Koballa & Glynn, 2007), and these theories include SDT (Deci & Ryan, 2000, 2008; Ryan & Deci, 2002). SDT maintains that an understanding of human motivation requires a consideration of the innate psychological needs that are essential for ongoing psychological growth, integrity, and well-being (Deci & Ryan, 2000, 2008; Ryan & Deci, 2002). These psychological needs include the needs for (1) *autonomy*, the desire to regulate and control one's own behavior; (2) *competence*, the desire to engage in challenging tasks; and (3) *relatedness*, the desire to seek attachments and to experience feelings of belonging and connection (Deci & Ryan, 2000; Ryan & Deci, 2002). According to SDT, a critical issue concerning the effects of the pursuit and attainment of goals involves the degree to which people can satisfy these basic psychological needs as they pursue and attain their valued outcomes (Deci & Ryan, 2000). SDT assumes that people are, by nature, active and self-motivated, curious and interested, vital, and eager to succeed (Deci & Ryan, 2008). However, people can also be alienated and mechanized or passive and disaffected. SDT accounts for these differences in terms of the types of motivation that result from the interaction between people's inherent active nature and the social environments that either support or thwart that nature (Deci & Ryan, 2008). Optimal development and

well-being are an expected outcome in an environment that facilitates the conditions that support need satisfaction, whereas degradation is an expected outcome in an environment that thwarts basic need satisfaction (Deci & Ryan, 2000, 2008).

Research indicates that many of the characteristics of inquiry-based learning, specifically those of open inquiry, are aligned with the tenets of SDT and are associated with enhanced student motivation to learn. These characteristics include conducting autonomous and self-regulated learning, conducting challenging and authentic tasks, exercising freedom of choice, and promoting opportunities to engage in science (Blumenfeld et al., 2006; Knutson, Smith, Wallert, & Provost, 2010; Parsons & Ward, 2011; Patrick, Mantzicopoulos, Samarapungavan, & French, 2008; Sadeh & Zion, 2009; Wijnia, Loyens, & Derous, 2011; Zion et al., 2004). In addition, inquiry-based learning enables students to engage in a task that aligns with their own interests, their challenges, and their sense of satisfaction, thus further enhancing student motivation (Hmelo-Silver, 2004).

However, scientific inquiry requires students to invest considerable mental effort and persistence to overcome challenges (Blumenfeld et al., 2006). Lehrer et al. (2008) indicated that providing students with opportunities to develop and sustain inquiry is an enduring pedagogical challenge. The reason is that students have difficulties in various aspects of the process. For example, *making sense* of a phenomenon through scientific operations can be overwhelming for students for several reasons: First, a gap may exist between students' intuitive thoughts about a phenomenon and the formalisms used to represent it in expert practice; second, observing core aspects of scientific situations requires substantial content domain-specific knowledge; and third, implementing the appropriate strategies necessary to guide sense-making requires explicit guidance and support (Quintana et al., 2004). In addition, students have difficulties in asking questions that are amenable to experimentation and meaningful conclusions (Krajcik et al., 1998). Other challenges include coordinating theory and evidence, understanding the logic of the experimental design and its necessary procedures, analyzing and interpreting evidence, constructing scientific explanations, and seeking evidence that might disconfirm favored theories (Kuhn, Black, Keselman, & Kaplan, 2000; Lehrer et al., 2008; Quintana et al., 2004). Finally, the ongoing need for *articulation and reflection* throughout the inquiry process can also pose obstacles for students in several instances: The goals for reflection are underrealized, students' work is focused on achieving quick outcomes, and support for reflection and for the correct form of articulation is lacking (Quintana et al., 2004). Students also encounter challenges that arise from the social dimension of the inquiry process and the discourse practices that the process entails, such as communicating their understanding and participating in argumentative discourses (Berland & Reiser, 2009; Reiser, 2004).

The conceptual and practical hurdles that students face when engaging in inquiry emphasize the complexity of the process (Hmelo-Silver et al., 2007). This complexity and the cognitive and mental challenges involved can lead to a counterproductive process (Kuhn et al., 2000). Such unsuccessful experiences can lead students to think that they are unable to successfully complete the task, thereby increasing students' frustration (Belland et al., 2013; Kirschner et al., 2006). From the SDT perspective, if students are overwhelmed by challenges, then their competency and autonomy may be hampered, and this situation affects their motivation to engage in the inquiry process. Indeed, research indicates the necessity to provide students with cognitive and motivational support to successfully engage in the inquiry process (Belland et al., 2013; Hmelo-Silver et al., 2007).

2.3 | Implications for teaching

Teachers play a crucial role during the open inquiry process by providing both cognitive and affective support for their student (Blumenfeld et al., 1991; Crawford, 2000; Urhahne, Schanze, Bell, Mansfield, & Holmes, 2010). In a constructivist classroom, in which learning is a constant process of effort and knowledge construction, students should be provided with extensive cognitive scaffolding and guidance to facilitate their learning (Hmelo-Silver et al., 2007; Kirschner et al., 2006). According to Palmer (2005), the role of teachers as motivators, in which they aim to encourage students and maintain their motivation at optimum levels throughout the learning process, is crucial.

Research indicates that educational interventions that are based on clear theoretical foundations or rationales can influence student motivation (e.g., Belland et al., 2013; Palmer, 2005; Veermans & Järvelä, 2004; Wigfield & Wentzel,

2007). SDT can have practical utility, providing a framework for teachers in supporting their students' motivation (Guay, Ratelle, & Chanal, 2008; Pintrich, 2003). Within the context of inquiry, teachers can support students' *autonomy* by taking the perspective of their students, offering opportunities of choice such as deciding on a topic or selecting learning activities, being receptive to students' questions and ideas, making learning relevant, and helping direct students' own learning (Belland et al., 2013; Blumenfeld et al., 2006; Wijnia et al., 2011). Students' autonomy can also be supported by the type of language and phrases used by teachers (Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004). Students' sense of *competence* is enhanced when teachers provide support through instruction in strategies and skills, model thinking, and decompose tasks (Blumenfeld et al., 2006; Wijnia et al., 2011). In addition, encouragement, the recognition of progress, and constructive feedback on students' work enhance students' perceptions of efficacy (Blumenfeld et al., 2006; Schunk & Miller, 2002; Urdan & Turner, 2005). Finally, students' need for *relatedness* is satisfied when teachers express respect, caring, and interest in a student's well-being (Blumenfeld et al., 2006).

In science education, the impact of motivationally supportive online learning environments remains largely unexplored (Chen & Jang, 2010). However, studies emphasize the central role that the tenets of SDT play in supporting student motivation in online discussions (Rienties et al., 2012; Rovai, 2007). For example, Chen and Jang (2010) found that support for autonomy and competence in an online environment positively affected students' perceived autonomy, relatedness, and competence. In turn, this need satisfaction positively affected student motivation. Similarly, Sloan (2015) found that the perceived quality of feedback that students received in an online discussion was associated with the tenets of SDT. Furthermore, using online dialogues between scientist-mentors and their students in an online inquiry-based learning environment, Scogin and Stuessy (2015) found a general positive association between scientist-mentor motivational support and student inquiry engagement. This trend was consistent despite the differences in the way the scientists supported the SDT tenets in their online mentorship.

3 | RESEARCH QUESTIONS AND HYPOTHESES

The primary assumption of this study asserts that student motivation throughout an open inquiry process is not the sole product of their engagement in an authentic and problem-based experience (Belland et al., 2013) but, rather, the interplay between the inquiry's characteristics and contextual factors, namely, the challenges that the students encounter during their inquiry process and the motivational support provided by teachers to their students. Examining this interplay and its effect on student motivation is at the core of this study. In conducting this examination, we depart from unitary attributions and adopt a broader perspective of student motivation as a context-dependent construct (Koballa & Glynn, 2007). The secondary assumption of this study asserts that open inquiry cannot be viewed as a single global concept. Rather, open inquiry is a process that engages students in various activities, practices, and thinking processes with different cognitive features and, consequently, different effects on student motivation (NRC, 2012a; Rönnebeck et al., 2016; Sandoval & Harven, 2011).

Based on these two assumptions, our study examines how the interplay of the contextual factors affects student motivation throughout an open inquiry as expressed in an online forum that accompanied the process. We selected SDT (Deci & Ryan, 2000) as the guiding framework for this study for two primary reasons: (1) Two of the components of this theory, autonomy and competence, constitute core characteristics of open inquiry; and (2) SDT has been used previously and was found to be appropriate for the assessment of online discourse (e.g., Chen & Jang, 2010; Scogin & Stuessy, 2015; Sloan, 2015; Xie, Debacker, & Ferguson, 2006). In accordance with the research hypotheses, we ask the following four specific research questions:

1. What are the patterns and shifts in students' unfolding temporal motivation as they engage in various cognitive tasks throughout the inquiry process?
2. How do contextual factors affect the shifts in student motivation?
3. What are the patterns and shifts in the motivational support provided by the teacher to the students throughout the various cognitive tasks of the inquiry process?

4. What is the relationship between student motivation and the motivational support provided by the teacher?

Open inquiry can engage students in the excitement of authentic science. However, open inquiry is also a challenging process that requires considerable cognitive investment and that is accompanied by various emotions and mixed feelings (Zion et al., 2004). Thus, we hypothesize that the students' motivation throughout the process will be impacted by the challenges posed to them by the different cognitive tasks and by their perceived ability to overcome these challenges. Aligned with SDT, we anticipate that the students' competence and autonomy will decrease when they encounter a challenge that they feel incapable of confronting. Similarly, as the students seek more guidance and support from their teacher, they will feel less motivated to engage in the inquiry process. Relying on research on the crucial role of teachers in providing students with cognitive, affective, and motivational support during inquiry (Crawford, 2007), we also hypothesize that teachers' responses that satisfy the students' needs for competence, autonomy, and relatedness will have a positive effect on student motivation (Ryan & Deci, 2000). Consequently, we anticipate a positive correlation between the teacher's support of student motivation, by meeting the students' psychological needs, and the students' motivation throughout the inquiry process.

4 | METHODS

This study tracked students who were engaged in a yearlong open inquiry process with one teacher. The students' expressions of motivation and the motivational support provided by their teacher were examined through their correspondences in an online asynchronous forum that accompanied the entire inquiry process. The forum provided a glimpse into the dynamics of the students' expressions of motivation and the teacher's motivational support during the inquiry process.

4.1 | Research context

The research sample consisted of a class of 37 high-achieving eighth-grade Israeli junior high school students. The students were engaged in a yearlong inquiry-based environmental program that was part of the students' mandatory science education curriculum. The program included monthly visits to "The Council for a Beautiful Israel," an organization aimed at improving the quality of life in Israel through environmental education. In addition, the program included social-scientific open inquiry projects that were conducted by the students under the supervision of their teacher at their school. In these projects, teams of students (mostly in pairs: $n_{pairs} = 17, n_{triplet} = 1, n_{total} = 18$) identified and examined real-life environmental issues related to their nearby surroundings and engaged in scientific practices through the process of inquiry (NRC, 2012a): The students generated research questions and hypotheses regarding their environment; they planned an investigation and developed their research tools according to their research question; they then conducted their investigation and collected data; they analyzed the data and drew conclusions; finally, they wrote a scientific report in which they summarized their research and communicated their results and conclusions. Based on their analysis, the students also advocated methods to address the environmental issues that they researched.

The teacher closely supervised and facilitated the entire process of the students, both during and after school hours. During school hours, the teacher conducted class sessions and individual meetings with each pair of students. These face-to-face meetings included theoretical and practical explanations, examples, and feedback. After school hours, the students received assistance and feedback from their teacher through the online asynchronous forum.

4.2 | Students' inquiry process

4.2.1 | Procedural aspects of the students' inquiry

According to the *Framework for K–12 Science Education* (NRC, 2012a), inquiry learning is a dynamic process that enables students to engage in the practices of science. Students' engagement in these practices "helps students understand

how scientific knowledge develops" and helps them gain "an appreciation of the wide range of approaches that are used to investigate, model, and explain the world" (NRC, 2012a, pp. 42). Research supports the notion that open inquiry is an ongoing process of contemplation and change (Zion et al., 2004) and highlights the fundamental role of supporting students during their engagement in the process (Kirschner et al., 2006; Hmelo-Silver, Duncan, & Chinn, 2007). Consequently, a major challenge that the researchers encountered in this study was how the teacher could support the students during the inquiry process in a way that ensured that the students were engaged in scientific practices in a productive and goal-oriented manner. Ideally, this engagement should not restrict their process to a step-wise one-way scientific method; it should simultaneously enable the students to experience the dynamics of an inquiry process. For this purpose, although instruction regarding the inquiry process was structured, the students were able to monitor previous outcomes and change them during the entire process.

In a recent literature review of inquiry-based learning, Pedaste et al. (2015) identified five distinct general inquiry phases that together form an inquiry cycle: orientation, conceptualization, investigation, conclusion, and discussion. Some of these phases are divided into subphases: The conceptualization phase is divided into two subphases, questioning and hypothesis generation; the investigation phase is divided into three subphases, exploration or experimentation, leading to data interpretation; and the discussion phase is divided into two subphases, reflection and communication. In this study, Pedaste et al. (2015) suggested a synthesized framework that describes an inquiry cycle in which all these phases and subphases are present.

In accordance with the framework suggested by Pedaste et al. (2015), the inquiry curriculum in this study included seven distinct phases. Notably, the phases also engaged the students in the various scientific practices defined by the *Framework for K–12 Science Education* (NRC, 2012a): (1) choosing a social-environmental issue as an inquiry topic and formulating the inquiry question; (2) generating hypotheses; (3) planning the investigation and developing the research tools, such as questionnaires, interviews, and observations; (4) conducting the literature review and the theoretical framework of the study and conducting the experiment; (5) analyzing and interpreting the data; (6) organizing a discussion; and (7) assembling all of the inquiry phases into a written report and reflecting upon the process. Table 1 links these seven phases to both the framework of Pedaste et al. (2015) and the main scientific practices that the students were engaged in while completing this phase. To advance from one phase to the next, the students required the teacher's feedback and approval. Such an approach enabled the teacher to closely monitor the students' progress within the inquiry process. The students were encouraged to examine their process; with the help of their teacher, the students performed ongoing monitoring of their inquiry, especially for coherence among the various phases. Throughout the process, the students documented their inquiry in a structured report that resembled a scientific article.

4.2.2 | Guiding the students' inquiries

Although open inquiry is a highly student-centered process in which students take responsibility for their learning (Herron, 1971; NRC, 2000; Schwab, 1962), researchers have underscored the importance of providing students with extensive scaffolding (Hmelo-Silver et al., 2007; Kirschner et al., 2006). Therefore, we developed a curriculum that included both theoretical and practical explanations concerning the procedural aspect of the inquiry process. This curriculum was based on central themes from the field of science education and inquiry-based learning, such as scientific practices (Osborne, 2014), the nature of science (Abd-El-Khalick, Bell, & Lederman, 1998), and the concepts of evidence and procedural understanding (Roberts, 2001).

4.2.3 | Supporting the students' metacognitive processes

As metacognitive support is essential to open inquiry (Keselman, 2003; Minner et al., 2010), this support was embedded within the inquiry process. This metacognitive support was based on the *Meta-CIC* model developed by Adler, Zion, and Mevarech (2016). The *Meta-CIC* model combines an explicit metacognitive guidance (*Meta*) and peer collaboration in *collaborating inquiry communities* (*CICs*) within an inquiry-based learning approach.

TABLE 1 An overview of students' inquiry process

General phase (Pedaste et al., 2015)	Phase definition (Pedaste et al., 2015)	Subphase definition (Pedaste et al., 2015)	Phases in the current study	Scientific practices (NRC, 2012a)
Orientation	The process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement	The process of generating research questions based on the stated problem	✓ Choosing a social-environmental inquiry issue as an inquiry topic and formulating the inquiry question	✓ Asking questions
Conceptualization	The process of stating theory-based questions and/or hypotheses	The process of generating hypotheses regarding the stated problem	✓ Generating the hypotheses	✓ Developing and using models
		The process of framing and developing the theoretical underpinning of the inquiry question and hypotheses	✓ Conducting the literature review and the theoretical framework of the study	
Investigation	The process of planning exploration or experimentation, collecting and analyzing data based on the experimental design or exploration	The process of systematic and planned data generation based on a research question	✓ Planning the investigation and developing research tools, such as questionnaires, interviews, and observations	✓ Planning and conducting investigations
		The process of designing and conducting an experiment to test a hypothesis	✓ Conducting the experiment and collecting data	
		The process of analyzing and interpreting the collected data and synthesizing new knowledge	✓ Analyzing and interpreting the data	✓ Analyzing and interpreting data
				✓ Using mathematics and computational thinking
Conclusion	The process of drawing conclusions from the data, comparing inferences based on data with hypotheses or research questions	The process of analyzing and interpreting the collected data and synthesizing new knowledge	✓ Organizing a discussion	✓ Constructing explanations
				✓ Engaging in an argument based on the evidence

(Continues)

TABLE 1 (Continued)

General phase (Pedaste et al., 2015)	Phase definition (Pedaste et al., 2015)	Subphase definition (Pedaste et al., 2015)	Phases in the current study	Scientific practices (NRC, 2012a)
Discussion	The process of presenting the findings of particular phases or the whole inquiry cycle by communicating with others and/or controlling the entire learning process or its phases by engaging in reflective activities	The process of presenting the outcomes of an inquiry phase or of the whole inquiry	✓ Assembling all of the inquiry phases into a written report and reflecting upon the process	✓ Communicating data

The *Meta* guidance supported the two major components of metacognition: *knowledge about cognition* and *regulation of cognition*. Students' *knowledge about cognition* was supported using a *strategy evaluation matrix* (SEM) designed to promote explicit declarative, procedural, and conditional knowledge about various learning strategies (Schraw, 1998). Students' *regulation of cognition* was supported using a combination of the *regulatory checklist* (RC) developed by Schraw (1998) and the *reflective metacognitive questions* (RMQ) developed by Mevarech and Kramarski (1997) and Zion et al. (2005): The RC enables students to implement a systematic regulatory sequence to help them control their performance through a set of explicit prompts (Schraw, 1998); the RMQ contains metacognitive questions that require students to reflect upon their learning process (Mevarech & Kramarski, 1997; Zion et al., 2005). (For examples of the SEM, RC, and RMQ, see Adler et al. (2016) and Zion, Adler, and Mevarech (2015).)

Peer collaboration was used to further support students' metacognition (Frith, 2012; Larkin, 2006; Nielsen, Nashon, & Anderson, 2009; Salonen, Vauras, & Efklides, 2005; Siegel, 2012). In the *Meta-CIC* model, students collaborate with each other using an innovative scheme that includes two levels of collaboration: the *collaborating inquiry* (*CI*) and the *CIC*. The *CI* refers to the collaborative relationships between a pair of students who work on the same inquiry project together. The *CIC* refers to the collaborative relationships among several pairs of students, with each pair working on different inquiry projects. These *CIC* interactions expand learning beyond the limitations of one pair by providing more opportunities for students to exchange insights, ideas, and strategies and to learn from each other's strengths and weaknesses (Lou, 2004; Lou & MacGregor, 2004). Furthermore, in the *CIC*, the context and progress of other working projects provide students with both motivational support and new insights (Lou, 2004; Lou & MacGregor, 2004).

4.2.4 | The accompanying asynchronous online forum

An asynchronous online forum accompanied the inquiry process. This forum served as a communication tool between the teacher and the students after school hours (see Figure 1). In the forum, students posed questions, requested help and guidance, shared their ideas, and monitored and compared their progress to that of others. All components of students' inquiry projects were uploaded to the forum for the teacher's examination throughout the entire inquiry process; the teacher closely monitored and evaluated each inquiry project and provided individual attention, support, and feedback for each of the student pairs (see also Zion, 2008). In addition to these personal interactions, the teacher regularly provided the students with an in-class overview of their progress in the inquiry project. All forum messages were recorded and served as the database for examining the students' and teacher's expressions of motivation.

{students} **Inquiry questions from ItaiX2**
Inquiry questions about antibiotics:

1. What is the relationship between health issues caused by air pollution and the heavy use of antibiotics?
2. What is the relationship between health-environment awareness about the damage caused by antibiotics to the human body and intelligent nutrition ?

Waiting for an answer…
ItaiX2

{teacher} **Excellent!**
The first research question requires biological research, and we've established that this is not the route we're taking. The second research question (I'll need to tweak it) certainly belongs in the social sciences, and it is also very interesting! Which research discipline have you decided to study?

{students}**A question from Itai & Ita**i
If we generate a hypothesis in which we compare our higher achieving 8th grade students to average students in another class, do we have to compare to another 8th grade class or can we make the comparison to a class in any other grade?

{teacher} **The answer is**…
When you want to compare, in every scientific field, you have to *control for variables*, which means – changing the variable which you are examining, while keeping the others constant. For example, in biology, if we want to examine how the amount of light affects the growth of plants, we need to examine the same type of plants (for example, roses), grow one plant with light, and the other without it. We will then see how this variable affects their growth. We can't take two different types of plants, because if we see differences when growing them with different amounts of sunlight, we won't know to which variable to attribute these differences: the plant types or the amount of sunlight? Likewise in the social sciences – if we want to compare 8th grade high achievers to average students, we must compare the high-achieving students to 8th grade average students. We can't compare 8th graders to 7th or 9th graders. Why can't we make this comparison? Because if we find differences, we won't know their source – the higher achievements or the grade level…Got it?

{students} **Yamit and Aviah research tools**
Performed with much success!

{teacher} **Great start…but much more work required!**
Good job – great try and start!
I can see that you understood the logic of the research tools table and the importance of coherence when designing a research project!

Here are some issues you should consider:
1. Review whether you have isolated correctly the dependent variable which you want to measure - you have performed this task correctly in all but one hypothesis.
2. Use as many different methodologies to examine each hypothesis – you have suggested surveys as a research tool for all of your hypotheses, but deleted the interview with the psychologist. However – this interview may provide you with insight on the topic from a more objective point of view! Try to add an interview with a student – it will be more or less the same questions. You won't have to do a significant amount of additional work and you will gain another research tool!
3. Note that for one of the hypotheses, you will need to compare between schools which have a book-rental program, and schools which lack such a program. Is this the comparison that you want to make?

Review and address the comments, and return to me a revised draft when you are finished.

Good Luck!!

FIGURE 1 Examples of teacher–student online dialogues

4.3 | Research tools

4.3.1 | The teacher motivational support indicators and the student expression of motivation indicators

Using the methodology applied by Scogin and Stuessy (2015), students' expressions of motivation and the teacher's motivational support were operationally defined as the words, phrases, or textual expressions of emotions that appeared in the online dialogues in the online forum that accompanied the inquiry process. Thus, the correspondences between the teacher and her students were examined for expressions of motivation. For this purpose, we developed two motivational indices: the *teacher motivational support indicators* (TeMSI) and the *student expression of motivation indicators* (SEMI).

Both the TeMSI and the SEMI are based on SDT (Deci & Ryan, 2000) and the community of inquiry (Garrison, 2011) frameworks and their application to an online environment by Scogin and Stuessy (2015). The TeMSI measure the motivational support provided by the teacher to the students in their online correspondences during the inquiry process, whereas the SEMI measure student motivation as expressed in the students' online correspondences. The three components of SDT, i.e., autonomy, competence, and relatedness, served as the major categories for both indices, and they were theoretically defined according to the work of Deci and Ryan (2000). These categories were further subdivided into indicators according to Scogin and Stuessy (2015).

4.3.2 | Autonomy

Following Scogin and Stuessy (2015), we included the following five indicators in the TeMSI as evidence for autonomy support provided by the teacher: (1) providing or acknowledging students' choice, (2) acknowledging students' ownership/control of the inquiry project, (3) using autonomy-supportive phraseology (i.e., not controlling language), (4) acknowledging negative comments or outcomes or encouraging work and progress, and (5) providing a rationale for some aspect of science in general or the inquiry experiment in particular. As an adaptation to our data, we added "using optimism" as a sixth indicator for evidence for the motivational support provided by the teacher. The TeMSI also include the following two indicators as evidence of the teacher's suppression of the students: (1) forbidding or limiting students' choice and (2) forbidding or limiting students' ownership/control of the project. The SEMI were constructed based on the teacher's supportive and suppressive indicators, with adaptations to enable their applicability to the students' expressions. To make these adaptations, the first and second researchers of this study examined the teacher–student correspondences in the context within the forum, focusing on the students' responses to the teacher's phrases that were indicated as supporting or suppressing autonomy. Two categories were generated: positive autonomy, in which the students expressed independence in problem solving, choice, and participation (Grolnick & Ryan, 1989), and negative autonomy, in which the students did not express independence in problem solving, choice, and participation. Based on the teacher's indicators, the indicators for positive autonomy included (1) demonstrating awareness of or expressing choice; (2) demonstrating awareness of or expressing ownership/control of the inquiry project; (3) expressing the volition to work diligently; and (4) expressing optimism. The indicators for negative autonomy included (1) expressing a lack of choice and reliance on the teacher; (2) expressing a lack of ownership/control of the project; (3) expressing tiredness, exhaustion, and careless work; and (4) expressing pessimism. Notably, students' expressions were coded within the context and in respect to the specific correspondence between the teacher and the students.

4.3.3 | Competence

Corresponding to Scogin and Stuessy (2015), we included three indicators in the TeMSI as evidence of competent support provided by the teacher: (1) asking content or process questions specifically relevant to the inquiry project that challenged the students, (2) offering explanations in response to the students' questions, and (3) providing positive feedback specifically related to the students' actions or statements. In addition, the TeMSI include one indicator for the teacher's suppression of students' competence: expressing mistrust in the students' abilities. The SEMI were constructed based on the teacher's supportive and suppressive indicators, with adaptations to enable their applicability to the students' expressions. As described above, concerning the development of the indicators for students' autonomy, we developed the SEMI for students' competence by examining the context of the teacher–student correspondences within the forum. Two categories were generated: positive competence, in which the students expressed that they were challenged by the teacher (Newman, 2008), and negative competence, in which the students expressed an inability to overcome difficulties or overwhelming challenges. Based on the teacher's indicators, the indicators for positive competence included (1) asking the teacher for explanations, (2) asking for feedback regarding actions or statements, and (3) expressing the students' capability to overcome challenges. The SEMI also included one indicator of negative competence: expressing a lack of success or the inability to overcome challenges. As with the category of autonomy, the students' expressions

were coded within the context and with respect to the specific correspondence between the teacher and the students.

4.3.4 | Relatedness

As in Scogin and Stuessy (2015), the categories for expressions of relatedness in the both the TeMSI and the SEMI included interpersonal, open, and cohesive communication categories (see also Garrison, 2011). In both the TeMSI and the SEMI, the indicators for interpersonal communication included (1) affective expression, including emotion, repetitious punctuation, conspicuous capitalization, and emoticons; (2) using humor, including teasing, cajoling, irony, understatement, and sarcasm; and (3) self-disclosure: presenting details of life outside of class. Five indicators were used to determine open communication in the TeMSI: (1) inviting and encouraging students' participation and interactions, (2) complimenting and expressing appreciation, (3) expressing agreement with the students, and (4) referencing the students' messages. Based on Garrison (2011, p. 37), "continuing a thread" was added as a fifth indicator of open communication. The same indicators were used in the SEMI, with an additional subdivision of whether the phrases were directed to the teacher or to other students. Three indicators were used to determine cohesive communication in the TeMSI: (1) using inclusive language; (2) using salutations, greetings, or phatics; and (3) using personal names. The indicators in the SEMI differed from those in the TeMSI in two respects: (1) There was an additional subdivision of whether the indicators were used in regard to the teacher or in regard to other students; and (2) cultural differences were considered. Because public, state-sponsored school students in Israel address their teachers by their first names, this indicator was not included in the SEMI since it may not be a reliable indicator of relatedness and cohesive communication. As with the other categories, students' expressions were coded within the context and with respect to the specific correspondence between the teacher and the students.

Following the initial development of the indices, the first and second researchers of this study read *100* out of a total of 1,246 online messages by the teacher and 100 out of a total of 1,215 students' online messages. All messages from both the teacher and the students were coded according to the TeMSI and the SEMI. Discussions on the initial coding process led the researchers to formulate final defined indices and examples for the indicators. Table 2 describes the TeMSI and Table 3 the SEMI. Using the qualitative program MAXqda, the coding of all of the teacher's messages proceeded according to the TeMSI, whereas the coding of the students' messages proceeded according to the SEMI. A single message served as the unit of analysis. Using the TeMSI and the SEMI, the researchers assigned one, several, or no motivational criterion to each message (coding examples are presented in Table 2 for the TeMSI and in Table 3 for the SEMI). In addition, each message was coded for background data, which included the identification of the student pairs and the inquiry phase that the message addressed (1–7 described above). Thereafter, the total number of times that each motivational category and subcategory appeared in each student's messages for the various inquiry phases was retrieved from the MAXqda program and used for further quantitative analysis.

4.3.5 | Students' reflections

Throughout the process, the students documented their inquiry in a structured report that was modeled on a scientific article. In this report, the students articulated the inquiry question, theoretical background, hypothesis, research tools, data analysis, discussion, and conclusions. In addition, the students wrote a summary essay. In this essay, the students reflected and described their personal perspectives on their inquiry process and addressed the conflicts and difficulties that they encountered and the strategies that they implemented throughout the process.

4.3.6 | Students' personal interviews

We conducted semistructured interviews with randomly chosen students ($n = 8$). In the interviews, the students reflected upon their personal experience of the inquiry process. The students addressed their conflicts and difficulties and detailed their project management activities throughout the inquiry process.

TABLE 2 The teacher motivational support indicators (TeMSI)

Categories (SDT) and indicators Based on Scogin and Stuessy (2015)	Examples
Autonomy: The degree to which socializing agents encourage independence and free choice (Grolnick & Ryan, 1989).	
Autonomy support provided by the teacher	
Providing or acknowledging the students' choice	✓ What have you decided?! Whatever you decide – I'm in!! (Rinat & Daniel, first phase)
	✓ You should choose the children's ages and consider – why did you choose these ages? How many age groups do you want to compare? (Liel & Yuval, first phase)
Acknowledging the students' ownership/control of the inquiry project	✓ And of course, throughout, continue to think about subjects and questions for your inquiry projects… (entire class, phase 1)
Using autonomy-supportive phraseology	✓ I liked the first question, because it has never been asked before, and because it is more original in my opinion – but it is up to you!! (Eden & Lior, first phase)
	✓ About unifying categories – I am not sure that it is always a good idea to unify all of the "to a great degree" and "to a lesser degree." See my notes and decide for yourselves (Or, Shir & Gil, phase 5)
Acknowledging negative comments or outcomes or encouraging work and progress	✓ Call me ASAP!!!! (Ben & Ben, third phase)
	✓ On to the last section of the inquiry – the Discussion!!! (Aviah & Yamit, fifth phase)
Providing a rationale for some aspect of science in general or the inquiry experiment in particular	✓ Now – how do you turn this into an inquiry question…? The help that I can offer – do not skip stages – write down "use of antibiotics" on a document, and start elaborating on the subject by asking questions from different points of view (Strategy Two in the paper I handed out). Post the questions here, and we will continue thinking together (Itai & Itai, first phase)
	✓ Let's go – and don't forget the camera for documenting! (Daniel & Ronen, third phase)
Using optimism	✓ First of all, replace despair with hope – you are doing excellent and methodical work! There is still work to be done on the survey, but I think that the difficult part is behind you… (Or, Shir, & Gil, fourth phase)
	✓ Remember – we are at the beginning of a journey. And in every journey – the first step is always the most difficult, and a lot of patience is required! (entire class, first phase)
The teacher's suppression of the student's autonomy	
Forbidding or limiting the students' choice	✓ Regarding the subjects: I have marked for you in the previous document topics that in my opinion are interesting and good for you to focus on, and they are not necessarily the topics you chose… (Rinat & Daniel, first phase)
	✓ In short – I am helping you make the choice – and I have corrected (for the last time!!) your hypotheses about the school (Rinat & Daniel, second phase)
Forbidding or limiting the students' ownership/control of the project	✓ If you post later – I will begin to deduct points. You will lose a point for every day that you are late…. (entire class, first phase)

Continued

TABLE 2 Continued

	✓ It took me a while but I eventually decided to change your inquiry question, because the hypotheses were inappropriate for this question. I changed the term "environmental awareness" to "form of environmental harm," so that the first three hypotheses, with minor changes in articulation, are appropriate for the question (Nadav & Omri, second phase)
Competence: Giving attention to students and providing feedback/explanations that challenge students without offering definitive solutions (Newman, 2008)	
Competence support provided by the teacher	
Asking challenging content or process questions that are specifically relevant to the inquiry project	✓ Think – is your variable really "age"? Or does the age represent something else and it is this "something" you wish to examine? (Liel & Yuval, first phase)
	✓ First ask yourselves – are you really following the flow chart? (Guy & Daniel, fourth phase)
Offering explanations in response to student questions	✓ Are you asking if the highlighted sentence is important? If so, then yes, indeed!! It is the most important sentence!! It is the one that carries you to the Discussion, and it is therefore critical!!! (Lior & Sapir, fifth phase)
Providing constructive feedback related to the students' actions or statements	✓ Call me ASAP – your work is disorganized… the main problem is that you are not aiming for the measured factor appropriately. In my opinion, this is partly the result of a disorganized plan (Adam & Sandra, third phase)
	✓ I heard today from everyone by all media possible – online forum, email, SMS, mobile, landline… (an idea for an inquiry question: What is the relationship between technological advancement and the teacher's sanity…????) It was fun to see everyone working, putting in the effort, coping and most importantly – never giving up! (entire class, seventh phase)
The teacher's suppression of the student's competence	
Expressing mistrust in the students' abilities	✓ No example available
Relatedness: Relatedness involves developing secure and satisfying connections with others in one's social milieu (Deci et al., 1991)	
***Interpersonal Communication:* The teacher is responsible for establishing an open academic climate and academically purposeful communication … Creates a climate and sense of belonging to the group and its educational goals (Garrison, 2011)**	
Affective expressions include emotion, repetitious punctuation, conspicuous capitalization, and emoticons	✓ Hip hip hooray!! (Rinat & Daniel, first phase)
	✓ I feel bummed coming in for the 1st class and then waiting for nothingggg… (Itai & Itai, Guy & Daniel, fifth phase)
	✓ Great!!!! (Lior & Sapir, sixth phase)
Using humor	✓ Good jobs guys! Welcome to the "Excellence" Club! (entire class, seventh phase)

Continued

TABLE 2 Continued

	✓ You can't find the file?… My grandmother used to say: If you went to the beach, you wouldn't find any water.… Your file is the one with the fish below!!!!!! (Moshe & Omer, first phase)
Self-disclosure: presenting details of life outside of class	✓ Yeah, it is the same as in my advanced age of 34 years…
	✓ The last (and only) time I attended a soccer match was in Maracanã Stadium in Brazil – Rio vs. Sao Paolo… is it the same quality…?? (Ronen & Daniel, fourth phase)
***Open communication*: The teacher establishes trust between the online participants and involves reciprocity, acceptance, and inclusiveness. Furthermore, open communication includes inviting further participation and elaboration, complimenting previous contributions, and expressing agreement (Scogin & Stuessy, 2015)**	
Inviting and encouraging the students' participation and interactions	✓ Be in touch with me throughout the process so that I can make sure you are on the right path (entire class, first phase)
	✓ You are welcome to call me at any hour within this timeframe and I will be happy to assist! (entire class, fifth phase)
Complimenting and expressing appreciation	✓ Best of luck! (Ronen & Daniel, third phase)
	✓ Way to go, I am very proud of you! (Daniel & Shiraz, sixth phase)
Expressing agreement with the students	✓ When you're right, you're right (entire class, first phase)
	✓ True, but you'll make it! (Adam & Sandra, sixth phase)
Referencing the students' messages	✓ Notice also the document uploaded by Daniel and Rinat – it contains enough ideas to keep a whole class busy!! And naturally – thank you! (entire class, first phase)
	✓ Look at my comments to your previous message!! (Ronen & Daniel, first phase)
Continuing a thread	✓ I have read and found it very interesting – you will surely retrieve a lot of information for your literary review! (You will soon find out what that is…)! (Aviv & Amit, first phase)
***Cohesion Communication*: Group cohesion is the dynamic state that social presence is attempting to achieve. It is cohesion that sustains the commitment and purpose of a community of inquiry (Garrison, 2011)**	
Using inclusive language	✓ Good Luck to us aaall! (entire class, seventh phase)
Using salutation, greetings or phatics	✓ Have a great week everyooone! (entire class, sixth phase)
	✓ Good Night everyone, pleasant dreams (entire class, seventh phase)
Using personal names	✓ Ram, Ben, Orr and Nir, Dan and Tamir – post your inquiry questions soon, otherwise you will open a gap from the rest of the class! (entire class, second phase)

TABLE 3 The student expressions of motivation indicators

Categories (SDT) & indicators Based on Scogin and Stuessy (2015)	Examples
Autonomy: The students express independence and freedom of choice (Grolnick & Ryan, 1989)	
Students' positive autonomy	
Demonstrating awareness of or expressing choice	✓ I eventually chose the inquiry question: What is the relationship between Passover and the environment? (Ben-Or & Tamir, second phase)
	✓ We omitted the questions we found unnecessary, and made corrections according to your feedback (Eden & Lior, third phase)
Demonstrating awareness of or expressing ownership/control of the inquiry project	✓ We saw the waiters and conducted the observations. We plan to conduct the observations on the luxury restaurant on Wednesday (Daniel & Shiraz, fourth phase)
Expressing the volition to work diligently	✓ Expecting your speedy reply (Liel & Yuval, first phase)
	✓ We'll repair and post to the forum ASAP!!! (Aviah & Yamit, second phase)
Expressing optimism	✓ Here is a new and better document!!!!! (Aviah & Yamit, first phase)
	✓ I can smell the trophy!! (Or, Shir & Gil, third phase)
Students' negative autonomy	
Expressing a lack of choice and reliance on the teacher	✓ Who is my assignment partner? (Adam & Sandra, first phase)
Expressing a lack of ownership/control of the inquiry project	✓ We submitted the outline, but you changed the inquiry question and the hypotheses (Yuval & Ofir, first phase)
	✓ I need help with the discussion, and you are not answering. You told us to be in touch but you do not respond… (Liel & Yuval, sixth phase)
Expressing tiredness, exhaustion and careless work	✓ If this is still not goooood enough I will hang myself (Rinat & Daniel, second phase)
	✓ The research tools… exhaustinggggg work…. I am still at Aviv's (It is Amit writing) (Aviv & Amit, third phase)
Expressing pessimism	✓ Pleassssse, I have no more energy… I am swamped with exams (Adam & Sandra, second phase)
	✓ Sorry for the delay, but we have a ton of worksheets and exams and it is difficult to stay on schedule… (Adam & Sandra, third phase)
Competence: The students are challenged by the teacher (Newman, 2008)	
Students' positive competence	
Asking the teacher for explanations	✓ We sent you the table of research tools and you sent us corrections, but we don't know how to proceed so we'd appreciate some help (Eden & Lior, third phase)
Asking for feedback regarding actions or statements	✓ I hope this is what you meant. If not, I will be happy to make corrections (Ben & Ben, first phase)

Continued

TABLE 3 Continued

	✓ We chose the inquiry question: What is the relationship between children's age and their social involvement? What do you think? (Liel & Yuval, first phase)
Expressing the students' capability to overcome challenges	✓ Finally, the discussion!!!! I hope it is good, it was really exhausting!! (Adam & Sandra, sixth phase)
	✓ After an especially difficult and demanding effort… we're dooone!!! XDDDD (Aviah & Yamit, sixth phase)
Students' negative competence	
Expressing a lack of success or the inability to overcome challenges	✓ We failed with the developing research tools to Hypothesis 2 despite your phone help (Guy & Daniel, third phase)
Relatedness: Relatedness involves developing secure and satisfying connections with others in one's social milieu (Deci et al., 1991)	
Interpersonal Communication: **Responsible for establishing an open academic climate and academically purposeful communication… Creates a climate and sense of belonging to the group and its educational goals (Garrison, 2011)**	
Affective expressions include emotion, repetitious punctuation, conspicuous capitalization, and emoticons	✓ Hope we aced the assignment… XD (Aviv & Amit, third phase)
	✓ Here!! We want a medal!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!:D!!!!!!!! !! (Nadav & Omri, seventh phase)
Using humor	✓ 26 pages of pure evil (Liel & Yuval, fifth phase)
	✓ Surprise! It's Or. We decided to exchange roles… (Or, Shir & Gil, fourth phase)
Self-disclosure: presenting details of life outside of class	✓ We both have the flu; we'll try to complete the assignment tomorrow! (Yuval & Ofir, third phase)
	✓ I tried calling you as many as ten times. It felt quite embarrassing…Please don't think we hung up the phone deliberately, ha, hahaha (Lior & Sapir, third phase)
Open communication**: Establishes trust between the online participants and involves reciprocity, acceptance, and inclusiveness. Furthermore, open communication includes inviting further participation and elaboration, complimenting previous contributions, and expressing agreement (Scogin & Stuessy, 2015)**	
Directed to the teacher OR Directed to a student	
Inviting interactions with the teacher	✓ We are back at the online forum…What else is there to do? (Eden & Lior, fourth phase)
Inviting interactions with other students	✓ Can someone explain to me how we should separate the files for the research tools? (Ben & Ben, third phase)
Complimenting and expressing appreciation to the teacher	✓ Thank you for the reply! We will certainly use your advice! (Yuval & Ofir, first phase)
Complimenting and expressing appreciation to other students	✓ Listen, this turned out awesome:)… (Aviah & Yamit, fourth phase)

Continued

TABLE 3 Continued

	✓ Good Luck to us all in the future…! (Aviv & Amit, first phase)
Expressing agreement with the teacher	✓ 'We agree with the point that you raised (Ben & Ben, first phase)
	✓ And by the way, it would be great if we generate a hypothesis that includes the factory manager, because that was indeed the initial idea! (Aviv & Amit, third phase)
Expressing agreement with other students	✓ You are very very very right (Or, Shir & Gil, first phase)
	✓ Yes we need to post the inquiry questions tomorrow (Ben & Ben, first phase)
Referencing the teacher's messages	✓ Visually:
	1. Go over the entire document – make sure everything is written with the same font, 12 pt, space 1.5, and no unnecessary gaps between lines. **Done** :)
	2. Some numbering/bullet points were transferred when copying/pasting from the Internet – fix this! **Fixed** :)
	3. Add images throughout the text – make it colorful and interesting! **Added** :) (Guy & Daniel, fourth phase)
Referencing other students' messages	✓ Ignore the above posting!!! It's only a conclusion (Liel & Yuval, seventh phase)
Continuing a thread of the teacher	✓ Thank you very much. We'll search the document you sent us for new ideas (Rinat & Daniel, first phase)
Continuing a students' thread	✓ We reviewed the document and accepted your corrections! (Moshe & Omer, second phase)
	✓ I liked your nickname- ItaiX2 (Or, Shir & Gil, first phase)
	✓ Lior, what happened to you? Since when is the word HYPOTHESIS written with an A? (Yuval & Ofir, second phase)
***Cohesion Communication*: Group cohesion is the dynamic state that social presence is attempting to achieve. It is cohesion that sustains the commitment and purpose of a community of inquiry (Garrison, 2011)**	
Using inclusive language	✓ If anyone needs help we're here!! It would really help us!! (Or, Shir & Gil, third phase)
Using salutation, greetings or phatics toward the teacher	✓ Hey! (Aviv & Amit, first phase)
	✓ And… happy holiday!!!! (Lior & Sapir, fifth phase)
Using salutation, greetings or phatics toward other students	✓ Hey Ron (Aviah & Yamit, third phase)
	✓ Shabbat Shalom everybody! (Aviv & Amit, seventh phase)

4.4 | Data analysis

Three sets of data were defined: the students' expressions of motivation throughout the inquiry process, the teacher's motivational support provided to the entire class, and the teacher's motivational support provided to the pairs of students. The data sets were analyzed by content category with chi-square tests (χ^2) by inquiry phase. For chi-square tests to be valid, these analyses were conducted only within categories of sufficient variance. *Z* tests for proportions were used to compare the total number of messages over time among the categories and between the teacher and the students. Spearman correlations were calculated to assess the relationships between the motivational support provided by the teacher and the students' expressions of motivation in matching and cross-lagged inquiry phases.

To answer the second research question concerning the contextual factors that affect the shifts in student motivation, we developed a qualitative approach. A "team motivation profile" was composed for each pair of participating students. This motivational profile was developed by calculating the percentage of team messages that included each SDT tenet (i.e., positive and negative autonomy, positive and negative competence and relatedness) for each inquiry phase (1–7, as described in the Methods section). Based on these percentages, we plotted a graph that represented the team's shifts in motivation throughout the inquiry process according to SDT. Thereafter, two teams were selected for a triangulation between their motivational profiles, personal interviews, and reflections. The data were analyzed in two steps: In step one, the teams' motivational profile was examined to obtain insights into the dynamics of the students' expressions of motivation throughout the inquiry process. Then, in step two, the students' personal interviews and reflections were examined to obtain supporting evidence of the observed dynamics of student motivation and to determine the possible reasons for these fluctuations.

5 | RESULTS

5.1 | Patterns and shifts in students' unfolding temporal motivation as they engage in various cognitive tasks throughout the inquiry process

To examine the patterns and shifts in the students' unfolding temporal motivation throughout the seven phases of the inquiry process, the students' messages were examined using the SEMI and analyzed with chi-square tests (χ^2) (Table 4, Figure 2).

The results in Table 4 indicate that the students posted a total of 1,215 messages, almost all of which included a *relatedness* component (91%). In addition, the students' messages included *positive competence* (29%) and *positive autonomy* (18%). A few messages included contents related to *negative competence* (4%) and *negative autonomy* (3%). The percentage of messages that included *relatedness* was highest (91%), followed by *positive competence* (29%), and *positive*

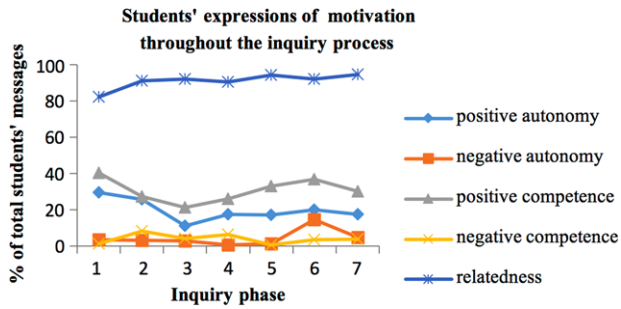

FIGURE 2 Dynamics of the students' expressions of motivation [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Number of student messages by SEMI category and inquiry phase[a]

Inquiry phase	Number of messages, *n* (%)	Positive autonomy, *n* (%)	Negative autonomy, *n* (%)	Positive competence, *n* (%)	Negative competence, *n* (%)	Relatedness, *n* (%)
1	179 (14.73)	53 (29.61)	6 (3.35)	72 (40.22)	2 (1.12)	147 (82.12)
2	124 (10.21)	32 (25.81)	4 (3.23)	34 (27.42)	10 (8.06)	113 (91.13)
3	346 (28.48)	38 (10.98)	10 (2.89)	73 (21.10)	14 (4.05)	319 (92.20)
4	208 (17.12)	36 (17.31)	1 (0.48)	54 (25.96)	13 (6.25)	188 (90.38)
5	158 (13.00)	27 (17.09)	2 (1.27)	52 (32.91)	1 (0.63)	149 (94.30)
6	90 (7.41)	18 (20.00)	13 (14.44)	33 (36.67)	3 (3.33)	83 (92.22)
7	110 (9.05)	19 (17.27)	5 (4.55)	33 (30.00)	4 (3.64)	104 (94.55)
Total	1,215 (100.0)	223 (18.35)	41 (3.37)	351 (28.89)	47 (3.87)	1,103 (90.78)
$\chi^2(6)$	255.99, $p < .001$	26.99, $p < .001$	—	18.89, $p = .004$	—	—

[a]The inquiry phases are as follows: (1) choosing an inquiry topic and formulating the inquiry question, (2) generating hypotheses, (3) planning the investigation and developing the research tools, (4) conducting the literature review and the theoretical framework of the study and conducting the experiment, (5) analyzing and interpreting the data, (6) organizing a discussion, and (7) assembling all of the inquiry phases into a written report and reflecting upon the process.

autonomy (18%). The lowest percentages of messages included *negative competence* (4%) and *negative autonomy* (3%). The difference between these frequencies was significant (Friedman's test, $p < .001$).

The differences in the students' messages among the various inquiry phases were significant regarding *positive autonomy* and *positive competence*. The percentage of the *positive autonomy* component was the highest in phases 1 and 2 (30% and 26%, respectively). This percentage was higher than that in phase 6 (20%) and higher than the percentages in phases 4, 5, and 7 (approximately 17%, $p < .05$). The percentage of the *positive autonomy* component was the lowest in phase 3 (11%, $p < .05$). The highest percentages for the *positive competence* component were obtained for phases 1 and 6 (40% and 37%, respectively). Midrange percentages were found for phases 5 and 7 (33% and 30%, respectively), followed by the percentages in phases 2 and 4 (27% and 26%, respectively). The *positive competence* component obtained the lowest percentage in phase 3 (21%) (significance levels: phase 6 vs. phase 7, $p < .01$; phase 5 vs. phase 2, $p < .05$; phase 4 vs. phase 3, $p < .05$).

Differences were not calculated for the *relatedness* component due to the low and insufficient variance (82–95% in the seven phases) or for *negative competence* and *negative autonomy* (0.50–14% in the seven phases). Regarding the *relatedness* component, although a chi-square analysis could not be performed, this component appears to be the lowest in the first phase (82%). Nonetheless, the component stabilizes across the six remaining phases (91–95%). The percentage of the *negative autonomy* component was the highest in phase 6 (14%) and stable across the remaining phases (0.50–5%). Similarly, the percentages for the *negative competence* component ranged between 0.50% and 8%.

5.2 | Contextual factors that affect the shifts in student motivation

Two teams were selected for a qualitative analysis of their motivational profiles: the case of Or, Shir and Gil (Team OSG) and the case of Yuval and Ofir (Team YO).

5.2.1 | The case of team OSG

Figure 3 describes this team's motivational dynamics. As indicated by the graph, specifically by the trend in the students' expressions of *positive autonomy* and *positive competence*, the team's expressions of motivation were not uniform throughout the phases of the inquiry process. The initial decrease in the students' motivation can be identified in the third phase, namely, planning the investigation and developing the research tools. This decrease corresponds to the decrease in student motivation expressed by the entire class (see Figure 2). The students' expressions of *positive autonomy* and *positive competence* remained low in the fourth phase, which included conducting the literature review and the

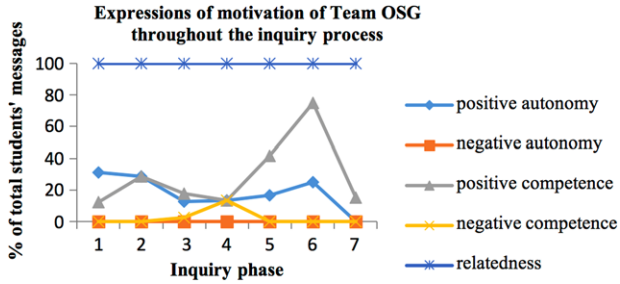

FIGURE 3 Dynamics of expressions of motivation of Team OSG [Color figure can be viewed at wileyonlinelibrary.com]

theoretical framework of the study and conducting the experiment. In this phase, expressions of *negative competence* were also present in the team's online messages. This trend changed in the fifth phase when the group analyzed and interpreted their data, with an observed increase in the team's expressions of *positive autonomy* and *positive competence*, reaching a peak in both of these components in the sixth phase, when the group members organized their discussion. A second decrease in the students' expressions of motivation was observed in the seventh phase, the final phase, when the students assembled all of the inquiry phases into a written report and reflected upon the process. As observed for the entire class, all of Team OSG's messages contained expressions of *relatedness*, and its messages did not contain expressions of *negative autonomy*.

In their written reflections, Team OSG referred to the difficulties and challenges that accompanied the inquiry process. Their reflections highlight the potential barriers to student motivation throughout the extensive and demanding process:

> *The study led to disagreements between us since each of us thought that she is correct and tried to persuade the others to accept her viewpoint (maybe we will eventually become lawyers instead of researchers or scholars …). During the process, we experienced both heated arguments and sentimental reconciliations… Many of the difficulties were due to the characteristics of our group members, for example, perfectionism (Or). Decision making was among the main difficulties we encountered. For example, selecting the inquiry topics/the inquiry question/hypotheses… However, despite the difficulties and arguments, the inquiry process contributed much to our learning abilities and emphasized the value of* ***responsibility***.

The difficulties that emerged from this team's reflections were echoed in Or's personal interview. She mentioned the challenges that accompanied the inquiry process, such as maintaining the schedule, working and collaborating with the partners, and using the computer throughout the entire process. She also mentioned the arguments and the subsequent breakdown in the personal relationships with the partners. In addition, Or specifically referred to the difficulties that she encountered during the preparation of the literature review (fourth phase):

> *Conducting the literature review was a long process … You have to think and understand what you are doing and not just "cut-and-paste" information … I, for example, took some books from the library, and I read and read and highlighted important sections and rephrased the information, in my own words, based on what I understood … and then, my partners found my work unacceptable, and I had to redo the whole process!*

5.2.2 | The case of team YO

Figure 4 describes this team's motivational dynamics. As in the previous case study, the team's motivational graph indicates that the expression of motivation varied greatly throughout the inquiry phases. We observed two dramatic decreases in the students' expressions of motivation: in the *positive autonomy* and *positive competence* components. After an increase in the students' expressions of these components in the second phase (generating hypotheses), an initial decrease occurred in the third phase (planning the investigation and developing the research tools). Furthermore, in

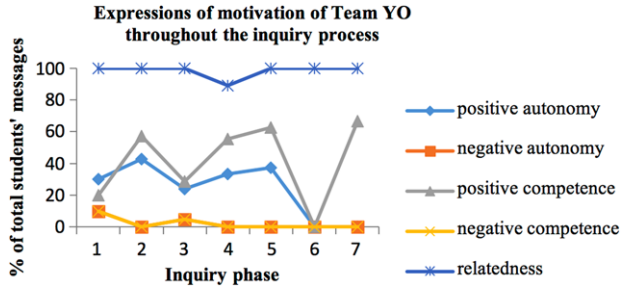

FIGURE 4 Dynamics of expressions of motivation of Team YO [Color figure can be viewed at wileyonlinelibrary.com]

this third phase, the team expressed *negative autonomy* and *negative competence*. The second decrease occurred toward end of the inquiry process, in phase 6 (organizing the discussion). This trend changed in the seventh and final inquiry phase (assembling all of the inquiry -phases into a written report), as the team's expressions of *positive competence* increased and reached a peak. Similar to Team OSG, nearly all of the YO team's online messages contained expressions of *relatedness*.

In their reflections, Team YO described the inquiry's challenges and the characteristics that the team members learned about themselves from their engagement in the inquiry process:

> *We faced many difficulties and dilemmas during the inquiry process, from the necessity to choose an inquiry topic to the discussion at the end of the process. At the beginning, everything seemed perfect and easy until we reached the more complex phases, such as developing our research tools. We had to write and review our research tools more than five times. Eventually, we reached the "king's road"; we began to stabilize and figure out how to improve our collaboration. Consequently, we discovered new traits of ourselves, namely, tolerance, helpfulness, competence, will power, faith, confidence, and responsibility … In the future, we will never give up, even when things become difficult. We enjoyed the inquiry process, and we do not regret the difficulties we experienced.*

In Ofir's personal interview, after submitting the inquiry report, she asserted the following:

> *During the process, we had many difficulties that we tried to avoid. However, regarding the difficulties we encountered, we often succeeded in coping with them appropriately, finding solutions, and continuing our work … Our inquiry report is comparable to a plant that we nurtured during the year; at the end of the year, the plant has blossomed and flowered. We have reached the desired outcome ….*

Ofir's reflection underscores the team's sense of satisfaction upon completing the inquiry process, and it is compatible with the increase in the students' expressions of motivation observed in the seventh phase (see Figure 4).

In summary, while Team OSG realized the important contribution of the inquiry to its members' learning, these students also acknowledged the numerous challenges that affected their motivation throughout the process. These challenges included *content-based challenges*, such as generating and deciding on the inquiry topic, question, and hypotheses; *process-based challenges*, such as maintaining the schedule, working with technology, and applying effective learning strategies; and *social challenges* associated with collaboration skills, such as solving disagreements, conducting productive arguments, and coordinating collaborations. As the students progressed through the inquiry process, more challenges were encountered, for example, Or's frustration from the collaboration with her peers when preparing the literature review. These accumulating challenges resulted in fluctuations in the team's expression of motivation and led to a decrease in the team's expression of *positive autonomy* and *positive competence* and an increase in expressions of *negative competence*, as evident in the conceptualization and investigation phases. Similarly, Team YO acknowledged the effect of the numerous challenges on its members' motivation; in particular, these students mentioned content-based challenges, such as the numerous revisions of their research tools. As in the case of Team OSG, these challenges led to a decrease in the team's expressions of *positive autonomy* and *positive competence* and an increase in expressions of *negative competence*, as evident in phases 3 and 6. According to the students, as they progressed through

TABLE 5 Summary and comparison of the motivational profiles of Team OSG and Team YO

Criteria	Team OSG (Or, Shir, and Gil)	Team YO (Yuval and Ofir)
Stability and fluctuation in team's motivation	Fluctuations in both teams' motivation throughout the inquiry process, especially for expressions of *positive autonomy* and *positive competence*	
Critical junctions in team's motivation	Two major decreases in the team's motivation: • Planning investigations and developing research tools • Generating a written report and reflecting upon the process in the final phase	Two major decreases in the team's motivation: • Planning investigations and developing research tools • Organizing the discussion
Negative emotions	Students *exhibited negative competence* when conducting the literature review and the theoretical framework of the study. The team did not express *negative autonomy* throughout the entire inquiry process.	Students exhibited both *negative competence* and *negative autonomy* both at the beginning of the process and at the planning of the investigation phases.
Reported challenges	Team members reported • Content-based challenges, such as generating and deciding on the inquiry topic, question, and hypotheses. • Process-based challenges, such as maintaining the schedule, working with technology, and applying effective learning strategies. • Social challenges associated with collaboration skills, such as solving disagreements, conducting productive arguments and coordinating collaborations.	The team members emphasized the content-based challenges that they faced and the demanding revision process. The team noted the improvement in their collaboration skills, the acquisition of effective learning and coping strategies, and the development of personal characteristics, which had a positive effect on their inquiry process.
Overall feelings	Both teams are proud and satisfied to have successfully met the challenges that they encountered in the inquiry process.	

the inquiry process, they improved their collaboration skills and acquired effective learning and coping strategies. The students indicated that these skills, strategies, and characteristics facilitated the process, contributed to their positive engagement in the inquiry and resulted in an increase in the team's expression of *positive autonomy* and *positive competence*. Table 5 summarizes and compares the patterns and fluctuations of the motivational profiles of Teams OSG and YO.

5.3 | Patterns and shifts in the motivational support provided by the teacher throughout the various cognitive tasks of the inquiry process

To examine the motivational support that the teacher provided the students throughout the inquiry process, the teacher's messages were separated according to their correspondents: messages containing motivational support directed to the entire class and messages containing motivational support by project directed to specific student pairs.

5.3.1 | Motivational support provided to the entire class

To examine the motivational support provided by the teacher to her entire class and the dynamics of this support throughout the entire inquiry process, the teacher's messages were examined using the TeMSI and analyzed with chi-square tests (χ^2) (Table 6, Figure 5).

TABLE 6 Number of teacher messages to the entire class by TeMSI category and inquiry phase[a]

Phase	Number of messages, *n* (%)	Positive autonomy, *n* (%)	Negative autonomy, *n* (%)	Positive competence, *n* (%)	Negative competence, *n* (%)	Relatedness, *n* (%)
1	52 (24.64)	14 (26.92)	2 (3.85)	6 (11.54)	0 (0.00)	52 (100.0)
2	38 (18.01)	19 (50.00)	1 (2.63)	4 (10.53)	0 (0.00)	38 (100.0)
3	43 (20.38)	29 (67.44)	3 (6.98)	12 (27.91)	0 (0.00)	43 (100.0)
4	19 (9.01)	8 (42.11)	3 (15.79)	5 (26.32)	0 (0.00)	19 (100.0)
5	21 (9.95)	11 (52.38)	0 (0.00)	4 (19.05)	0 (0.00)	21 (100.0)
6	7 (3.32)	5 (71.43)	0 (0.00)	2 (28.57)	0 (0.00)	7 (100.0)
7	31 (14.69)	18 (58.06)	1 (3.23)	6 (19.35)	0 (0.00)	31 (100.0)
Total	211 (100.0)	104 (49.29)	10 (4.74)	39 (18.48)	0 (0.00)	211 (100.0)
$\chi^2(6)$	46.39, $p < .001$	9.57, $p = .144$	—	5.75, $p = .452$	—	—

[a]The inquiry phases are as follows: (1) choosing an inquiry topic and formulating the inquiry question, (2) generating hypotheses, (3) planning the investigation and developing the research tools, (4) conducting the literature review and the theoretical framework of the study and conducting the experiment. (5) analyzing and interpreting the data, (6) organizing a discussion, and (7) assembling all of the inquiry phases into a written report and reflecting upon the process.

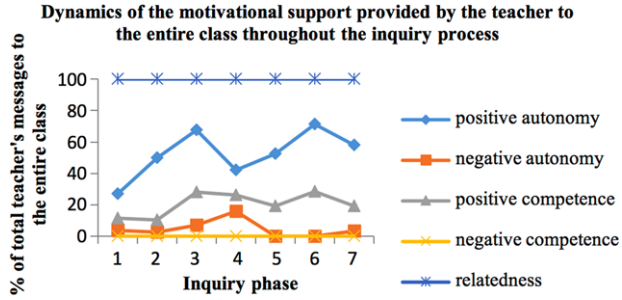

FIGURE 5 Dynamics of the motivational support provided by the teacher to the entire class [Color figure can be viewed at wileyonlinelibrary.com]

The results in Table 6 indicate that the teacher posted a total of 211 messages to the entire class, all of which included a *relatedness* component (100%). In addition, the teacher's messages included *positive autonomy* (49%), and *positive competence* (18%). Few correspondences included contents related to *negative autonomy* (5%), and none related to *negative competence* (0%). The percentage of messages that included *relatedness* was the highest (100%), followed by *positive autonomy* (49%) and *positive competence* (18%). The lowest percentage of messages included *negative autonomy* (5%) and *negative competence* (0%). The difference between these frequencies was significant (Friedman's test, $p < .001$).

We did not find any significant differences in the teacher's messages among the various inquiry phases regarding *positive autonomy* or *positive competence*. Nonetheless, a trend may be observed for *positive autonomy* according to which this component's percentage was the highest in phases 3 and 6 (67% and 71%, respectively), followed by phases 2, 5, and 7 (50% to 58%), then phase 4 (42%); the percentage was the lowest in phase 1 (27%). For *positive competence*, a trend may be observed according to which this component's percentage was the highest in phases 3, 4, and 6 (26–29%), followed by phases 5 and 7 (19%), and the lowest in phases 1 and 2 (approximately 11%).

The differences among the phases were not calculated for the *relatedness*, *negative autonomy*, and *negative competence* components due to the low or insufficient variance within the frequencies of these components (*relatedness* appeared in 100% of the messages, *negative autonomy* appeared in 0–16% of the messages, and *negative competence* did not appear in any of the messages). Regarding the *negative autonomy* component, although a chi-square analysis could

not be used due to the low percentages of occurrences, this component appears to be the highest in phase 4 (16%) and lower across all remaining phases (0–7%).

5.3.2 | Motivational support provided to specific pairs of students

To assess the motivational support provided by the teacher to specific pairs of students according to their projects and the dynamics of this support throughout the entire inquiry process, the teacher's messages were examined using the TeMSI and analyzed with chi-square tests (χ^2) (Table 7, Figure 6).

The results in Table 7 indicate that the teacher posted a total of 1,035 messages to specific pairs of students, almost all of which included a *relatedness* component (97–100%). In addition, the teacher's messages included *positive competence* (56%) and *positive autonomy* (54%). A few messages included contents related to *negative autonomy* (2%), and none related to *negative competence* (0%). The percentage of messages including *relatedness* was highest (99%), followed by *positive competence* (56%) and *positive autonomy* (54%). The lowest percentages were obtained for *negative autonomy* (2%) and *negative competence* (0%). The difference between these frequencies was significant (Friedman's test, $p < .001$).

We did not find any significant differences in the teacher's messages among the various phases of the inquiry phases regarding *positive autonomy* or *positive competence*. The differences among the phases for *positive autonomy* were marginally significant. A trend may be observed according to which this component's percentage was the highest in

TABLE 7 Number of teacher messages to specific pairs of students by TeMSI category and inquiry phase[a]

Phase	Number of messages, *n* (%)	Positive autonomy, *n* (%)	Negative autonomy, *n* (%)	Positive competence, *n* (%)	Negative competence, *n* (%)	Relatedness, *n* (%)
1	156 (15.07)	71 (45.51)	8 (5.13)	83 (53.21)	0 (0.00)	152 (97.44)
2	116 (11.21)	72 (62.07)	3 (2.59)	75 (64.66)	0 (0.00)	115 (99.14)
3	294 (28.41)	177 (60.20)	3 (1.02)	165 (56.12)	0 (0.00)	291 (98.98)
4	182 (17.58)	103 (56.59)	0 (0.00)	94 (51.65)	0 (0.00)	181 (99.45)
5	125 (12.08)	68 (54.40)	3 (2.40)	78 (62.40)	0 (0.00)	125 (100.00)
6	78 (7.54)	42 (53.85)	2 (2.56)	45 (57.69)	0 (0.00)	78 (100.00)
7	84 (8.11)	29 (34.52)	0 (0.00)	36 (42.86)	0 (0.00)	83 (98.81)
Total	1,035 (100.0)	562 (54.30)	19 (1.84)	576 (55.65)	0 (0.00)	1,025 (99.03)
$\chi^2(6)$	222.87, $p < .001$	11.63, $p = .071$	—	5.93, $p = .430$	—	—

[a]The inquiry phases are as follows: (1) choosing an inquiry topic and formulating the inquiry question, (2) ,generating hypotheses, (3) planning the investigation and developing the research tools, (4) conducting the literature review and the theoretical framework of the study and conducting the experiment, (5) analyzing and interpreting the data, (6) organizing a discussion, and (7) assembling all of the inquiry phases into a written report and reflecting upon the process.

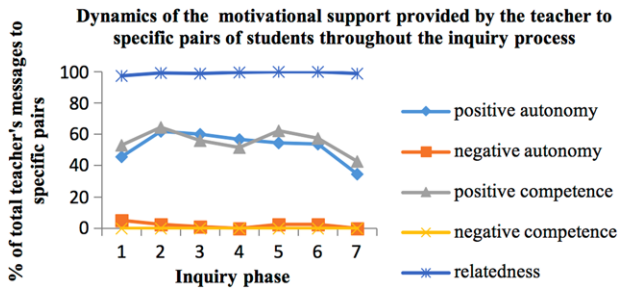

FIGURE 6 Dynamics of the motivational support provided by the teacher to specific pairs of students [Color figure can be viewed at wileyonlinelibrary.com]

phases 2 and 3 (62% and 60%, respectively), followed by phases 4–6 (54–57%), and then followed by phase 1 (45%). The lowest percentage was obtained for phase 7 (34%). For *positive competence*, a trend may be observed according to which the percentage was the highest in phases 2 and 5 (65% and 62%, respectively), followed by phases 1, 3, 4, and 6 (52–58%), and the lowest in phase 7 (43%).

The differences among phases were not calculated for the *relatedness*, *negative autonomy*, and *negative competence* components due to the low or insufficient variance of their expression.

The *negative autonomy* component appears to be stable across the seven inquiry phases, ranging between 0% and 5%. The *negative competence* component is a constant 0, and the *relatedness* component appears in almost all messages (97–100%).

5.4 | Relationship between student motivation and the motivational support provided by the teacher

First, we attempted to compare the number of messages composed by the teacher and by the students (Table 8). The results indicate that the total number of messages composed by the teacher ($n = 1{,}246$) and by the students ($n = 1{,}215$) is quite similar. However, the teacher's messages related to *positive autonomy* and *positive competence* significantly more than those of the students. Both the teacher and the students almost always included the *relatedness* component and rarely or never included the *negative autonomy* or *negative competence* components.

Second, to assess the relationships between the teacher's motivational support and the students' expressions of motivation, we calculated Spearman correlations (Table 9) throughout the inquiry phases by first matching the teacher's messages and the students' messages by the same phase of the inquiry process and then as cross-lagged correlations between the motivational support provided by the teacher in one inquiry phase and the students' expression of motivation in the subsequent phase. The correlations were calculated with categories of sufficient variance only.

The results indicate significant positive correlations between the motivational support provided by the teacher and the students' expressions of motivation, both within the same inquiry phase and in the subsequent inquiry phase. That is, the more the teacher provided motivational support to the students in terms of the *number of messages*, *positive autonomy*, and *positive competence*, the more the students expressed motivation to work in the same terms, both within the same inquiry phase and in the subsequent inquiry phase. The magnitude of the correlations is greater in the same inquiry phase than in the subsequent inquiry phase.

TABLE 8 Number of student and teacher messages by the SEMI and TeMSI categories

	Number of messages, *n* (%)	Positive autonomy, *n* (%)	Negative autonomy, *n* (%)	Positive competence, *n* (%)	Negative competence, *n* (%)	Relatedness, *n* (%)
Students	1,215 (100.0)	223 (18.35)	41 (3.37)	351 (28.89)	47 (3.87)	1,103 (90.78)
Teacher to specific pairs of students	1,035 (100.0)	562 (54.30)	19 (1.84)	576 (55.65)	0 (0.00)	1,025 (99.03)
Teacher to the entire class	211 (100.0)	104 (49.29)	10 (4.74)	39 (18.48)	0 (0.00)	211 (100.0)
Teacher Total	1,246 (100.0)	666 (53.45)	29 (2.33)	615 (49.36)	0 (0.00)	1,236 (99.20)
Students vs. Teacher to specific pairs of students	–	$Z = 17.83$, $p < .001$	–	$Z = 12.85$, $p < .001$	–	–
Students vs. Teacher total (specific pairs & entire class)	–	$Z = 18.12$, $p < .001$	–	$Z = 10.40$, $p < .001$	–	–

TABLE 9 Spearman correlations between the students' expressions of motivation and the motivational support provided by the teacher

	Students		
Teacher	**Number of messages**	**Positive autonomy**	**Positive competence**
	Same phase ($N = 126$)		
Number of messages	.89***	.56***	.61***
Positive autonomy	.70***	.37***	.49***
Positive competence	.82***	.56***	.58***
	Cross-lagged ($N = 108$)		
Number of messages	.25**	.34***	.27**
Positive autonomy	.24*	.27**	.27**
Positive competence	.30**	.37***	.32***

*$p < .05$, **$p < .01$, ***$p < .001$.

6 | DISCUSSION

Inquiry is regarded as an important and widespread constructivist approach to learning that fosters students' engagement in authentic science (NRC, 2000). Autonomy, self-regulated learning, and freedom of choice are regarded as major characteristics of this approach (Blumenfeld et al., 2006; Zion et al., 2004). Inquiry requires that students invest great effort and persistence (Blumenfeld et al., 2006). However, without the appropriate support from teachers, inquiry may actually lead to a sense of frustration on the part of students; furthermore, a lack of appropriate support may have a negative effect on students' motivation to engage in the inquiry process (Belland et al., 2013). Therefore, the teacher's role is crucial in providing students with motivational support and instruction to invest effort in the learning process. This study examines how the interplay between the characteristics and the contextual factors of open inquiry—the challenges encountered by the students and the motivational support provided by the teacher—affects student motivation, as expressed in an online environment throughout the inquiry process.

6.1 | Dimensions of student motivation and the motivational support provided by the teacher

Motivational research has shown that enabling students to make meaningful choices has a powerful influence and enhances their intrinsic motivation (Deci & Ryan, 2000; Ryan & Deci, 2002). Coupled with the cognitive opportunities that are provided by inquiry, these principles provide a strong argument for advocating inquiry-based learning in science education. However, the results of our study indicate that the students did not automatically embrace these characteristics of open inquiry; they did not express high levels of *positive competence* and *positive autonomy* in their online messages (29% and 18%, respectively). These low levels of the students' expressions of autonomy and competence are found despite the teacher's behavior, which can be described as promoting autonomy and supporting competence (Jang, Reeve, & Deci, 2010; Reeve, 2006). The teacher's expressions of *positive competence* and *positive autonomy* were prominent in the teacher's online messages (56% and 54%, respectively, when addressing specific pairs of students). Throughout the entire inquiry process, the teacher supported the students' competence by closely guiding the students, providing them with constructive, elaborate feedback concerning their inquiries, and offering detailed explanations as they progressed through the inquiry process (see the examples in Table 2). We did not identify occasions on which the teacher suppressed the students' competence. The teacher supported the students' autonomy by acknowledging the students' ownership of their inquiry, requesting their opinion on the topic under discussion, and enabling the students to make their own choice regarding the continuation of the inquiry process (see the examples in Table 2). We found only rare occasions on which the teacher suppressed the students' autonomy and limited their choice.

The students' educational context serves as a possible explanation for the gap between the teacher's strong support of the students' *positive autonomy* and *positive competence* and the students' inability to exploit their autonomy and freedom of choice. Ratelle, Guay, Vallerand, Larose, and Senécal (2007) suggested that students' motivational profiles are context sensitive. According to these authors, because school environments entail more extrinsic controls and rigid constraints, students develop, to some extent, controlled forms of motivation that enable them to meet these environmental demands (Ratelle et al., 2007). Although these motivational profiles may be productive in typical school settings, they may actually become counterproductive to students' successful engagement in processes such as open inquiry, in which student autonomy plays a central role. Thus, these controlled forms of motivation may also become a barrier to the successful implementation of open, autonomous types of learning. Ratelle et al. (2007) further indicated that employing strategies to promote students' development of autonomous motivation could affect students' motivational profiles (Ratelle et al., 2007). In this case, providing students with multiple and frequent student-centered curricula, in which students experience autonomy and develop autonomous forms of motivation (e.g., Krajcik & Czerniak, 2014), may improve their engagement in the autonomous process of open inquiry.

In addition, the results of our study indicate that expressions of *relatedness* were the most prominent in the online messages of both the teacher and the students. These expressions were significantly higher than their expressions of *positive competence* and *positive autonomy*. The data suggest that through the teacher's frequent use of expressions of relatedness, she helps sustain a social presence (Garrison, 2011) and helps create, enhance, and maintain a secure classroom environment. Creating a secure atmosphere is crucial to the inquiry process for several reasons. First, according to SDT, intrinsic motivation is more likely to flourish in a setting characterized by a sense of secure relatedness (Deci & Ryan, 2000; Patrick et al., 2008). Second, research indicates that people tend to internalize and accept as their own the values and practices of those to whom they feel connected and from settings in which they experience a sense of belonging (Niemiec & Ryan, 2009). Third, research indicates that self-regulation, learning, and performance are significantly affected by a sense of relatedness and impaired by a sense of social exclusion (Baumeister, DeWall, Ciarocco, & Twenge, 2005; Sheldon & Filak, 2008). Sheldon and Filak (2008) argued that "if performance/learning is viewed as the most valued outcome, then relatedness support may be the most important environmental provision of all" (p. 280).

In a previous study, Scogin and Stuessy (2015) found a positive association between the relatedness component and students' engagement in developing the inquiry question and engaging in the observations phases. In our study, no correlations could be calculated due to the insufficient variance in the students' expression of the relatedness component. However, our data indicate that the students' expression of relatedness increased between the first and second inquiry phases, suggesting that the students may have responded to the teacher's *relatedness* support by expressing more affect on their own. Further research is necessary to clarify this important finding.

6.2 | Patterns and shifts in student motivation and the motivational support provided by the teacher throughout the inquiry process

Although inquiry encompasses numerous characteristics that trigger student motivation (e.g., Blumenfeld et al., 2006; Knutson et al., 2010; Wijnia et al., 2011), the results of our study indicate that students' engagement in an inquiry process is not free of "motivational obstacles." Rather, student motivation is dynamic and includes several fluctuations throughout the inquiry process (see also Edelson et al., 1999). Because motivational fluctuations may become a serious barrier to students' successful engagement in the inquiry process (Veermans & Järvelä, 2004), it is important for educators to identify effective ways to strengthen their ability to demonstrate motivation (Wigfield & Wentzel, 2007).

Students' expressions of both *positive autonomy* and *positive competence* are the highest during the orientation phase of the inquiry process (Pedaste et al., 2015) In this phase, students' curiosity about a topic is stimulated, and their learning is challenged through a problem statement and the process of asking questions (NRC, 2012a; Pedaste et al., 2015). The characteristics of open inquiry that trigger student motivation are reflected in this phase and include autonomous and self-regulated learning, freedom of choice, and authenticity (Belland et al., 2013; Blumenfeld et al., 2006). The inquiry then progresses into the conceptualization and investigation phases in which students engage in various prac-

tices, such as developing models, planning and performing investigations, analyzing data, constructing evidence-based explanations, and engaging in an argument based on the evidence (NRC, 2012a; Pedaste et al., 2015). We identified a dramatic decrease in the students' expressions of *positive autonomy* and *positive competence* due to the content, process management, and social challenges that they encountered. An additional moderate decrease in students' expressions of *positive autonomy* and *positive competence* is evident in the last phases of the inquiry. The decrease in the students' expression of *positive autonomy* and *competence* is coupled with the appearance of expressions of *negative competence* and *negative autonomy*, which are rarely expressed throughout the process.

The shifts in the students' expressions of autonomy and competence and the pattern of student motivation identified here coincide with the framework developed by DeBellis and Goldin (2006) for affective pathways in mathematics education. According to this framework, all interactions with a heuristic begin with curiosity and puzzlement. In an idealized positive pathway, these feelings evoke exploratory problem-defining heuristics and motivate the problem solver to better understand the problem. When these procedures succeed, pleasure, elation, and satisfaction occur. In contrast, in a negative pathway, curiosity and puzzlement encode a search for appropriate or safe procedures rather than an exploratory opportunity. When these procedures fail, the resulting frustration turns into anxiety and despair. Applied to our results, the students' encounters with numerous challenges, the decrease in expressions of *positive autonomy* and *positive competence* and the appearances of *negative competence* and *negative autonomy* may indicate their turn to a negative pathway. This shift may lead to students' frustration with and failure to successfully engage in the inquiry process.

When student motivation decreases, the teacher's role as a motivator becomes even more crucial (Crawford, 2000). Indeed, the teacher in this study provided considerable motivational support to her students throughout the entire inquiry process. Although we did not observe significant differences, we observed a general trend by which the teacher provided more support in aspects of *positive autonomy* and *positive competence*, which coincided with the decreases in the students' expressions of motivation. The analysis of the teacher's online messages yielded a pattern by which the teacher simultaneously supports and combines both *positive autonomy* and *positive competence*. By using such a *guided autonomy* strategy, the teacher achieved two goals at once: First, she preserved the autonomous aspect of open inquiry that triggers students' intrinsic motivation by enabling them to decide on their inquiry process (Grolnik & Ryan, 1987; Vansteenkiste et al., 2004); second, the teacher provided the students with the necessary comprehensive guidance and support (including information, cues, prompts, examples, and feedback) to help ensure that they made informed decisions regarding their inquiries (Hmelo-Silver et al., 2007; Kirschner et al., 2006), and she preserved their intrinsic motivation and active task engagement (Mouratidis, Vansteenkiste, Michou, & Lens, 2013; Reeve, 2006). This strategy accords with the findings of Guay et al. (2008) and Jang et al. (2010), who demonstrated the importance of combining properly structured learning environments and supporting students' autonomy to improve learning.

Our results indicate a positive correlation between the teacher's motivational support, specifically regarding the *positive autonomy* and *positive competence* components, and the students' motivation. As the teacher provides more motivational support, the students engage in the positive affective pathway (DeBellis & Goldin, 2006). In line with previous research, these results underline the crucial role of the teacher as a provider of motivation to students within a complex learning environment.

7 | CONCLUSION

In a recent study, Kapon (2016) demonstrated an interaction of contextual factors in students' learning gains, passion, interest, and agency in regard to science. The results of this study expand Kapon's (2016) findings by revealing how the interplay of contextual factors affects student motivation throughout an open inquiry process. The results of our study also contribute to the literature on the fundamental role of the teacher as a motivational supporter and expand this role into a technological environment. According to Wentzel and Wigfield (2007), motivational interventions should be based on clear theoretical foundations or rationales to guide the intervention efforts. Our study indicates that SDT can provide a powerful framework to guide the efforts of teachers in supporting their students' motivation. DeBellis

and Goldin (2006) argued that the most important affective goals are not to eliminate frustration, remove fear and anxiety, or make the activities consistently easy and fun. Rather, the goals are to develop a perception by which the emotional feelings associated with an impasse or a difficulty are conducive to learning and accomplishment. Aligned with SDT, our study indicates that supporting students' autonomy, competence, and relatedness is a promising way to achieve this goal.

8 | LIMITATIONS AND FURTHER CONSIDERATIONS

An important limitation of our study involves the research population sample and the instructional method to which the students were exposed. The research sample included high-achieving and highly motivated students. Thus, these students' expressions of motivation and specifically the SDT components may be higher than those of the regular student population. In addition, the instructional method in this research included metacognitive support. Studies have indicated that students who display more adaptive self-regulatory strategies demonstrate better and higher motivation for learning (Schunk, 2005). Consequently, the metacognitive support embedded within the curriculum may have further biased the students' expressions of motivation upwards. If this upward bias is the case, the implementation of inquiry-based learning in other populations, such as heterogeneous or low-achieving students, may be even more difficult in terms of the students' motivation and engagement than demonstrated in this study. Moreover, in these settings, the implementation of inquiry-based learning will require special and focused support from the teachers. Thus, we urge science education scholars to conduct additional studies of student motivation and the support necessary to sustain student motivation. These studies are necessary to produce effective interventions within a complex learning environment, specifically within an inquiry-based learning environment for all students, regardless of their achievement levels.

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