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MOTIVATIONS AND SOCIAL PROCESSES

Supporting Deep Engagement: The Teaching for Transformative Experiences in Science (TTES) Model

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ABSTRACT
The Teaching for Transformative Experiences in Science (TTES) model was designed to facilitate the application of academic learning in students' everyday experiences. In the current study, we describe a 2-year design-based intervention that aimed to further develop and evaluate the TTES model. In the first year, a teacher implemented the TTES model in two of his four classes. The findings indicated enhanced engagement and learning, but primarily among students with higher prior engagement and learning. Insights led to revision of the TTES model. In the second year, the revised TTES model was implemented in all the teacher's classes, with another teacher's classes used for comparison. Intervention students demonstrated significantly greater learning and reported significantly higher levels of transformative experience than the comparison students.

KEYWORDS
Design-based research; engagement; instructional design; motivation; science education; transformative experience

Introduction

SCIENCE EDUCATION HAS the potential to enrich and expand students' everyday experience outside the classroom. Unfortunately, the transformative potential of science education often goes unrealized (Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010a), even in the context of effective science teaching methods such as inquiry (Pugh, 2002) and conceptual change instruction (Heddy & Sinatra, 2013). That is, students often fail to apply school learning outside of class and use it to enrich their interactions with the world. This outcome is unfortunate as prominent educators, such as Dewey (1938), have argued that enriching and expanding experience should be a central goal of education. In addition, researchers have found a positive connection between transformative learning experiences and the development of deep, enduring learning (Girod, Twyman, & Wojcikiewicz, 2010; Pugh, 2002; Pugh et al., 2010a, 2010b). Consequently, the science education community would be well served by the development and validation of an instructional model that fosters transformative learning.

Pugh and colleagues have initiated work in this area. They defined *transformative experience* as a particular instantiation of transformative learning in which students use science content learned in school to see and experience the world differently in their everyday, out-of-school lives (see Pugh, 2011). For example, a transformative experience is manifest by a student who learns about Newton's laws in science class and begins to see events of motion encountered in everyday experiences through the lens of Newton's laws (Pugh, 2004). Pugh and colleagues proposed the Teaching for Transformative Experiences in Science (TTES) model as a means of fostering transformative experiences (Pugh & Girod, 2007; Pugh et al., 2010b). The current study builds on this work by further developing and evaluating the TTES model. In line with design-based methodology (e.g., Collins, Joseph, & Bielaczyc,

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2004; The Design-Based Research Collective, 2003), the study was a 2-year recursive study in which results from year one were used to refine the model in year two.

The transformative experience framework

The transformative experience framework emerged from efforts to apply aspects of Dewey's work on learning and aesthetics to science education (Girod & Wong, 2002; Pugh, 2011; Wong, Pugh, & the Dewey Ideas Group at Michigan State University, 2001). Dewey (1938) was concerned that school learning was disconnected from everyday experience and sought to develop an educational philosophy in which they were more integrated. Contemporary research has contributed to understanding how everyday experience affects school learning (e.g., Bransford et al., 2006; Saxe, 1990; Smith, diSessa, & Roschelle, 1993); however, less research has investigated ways that in-school learning influences out-of-school experience (although there are notable exceptions, e.g., Barron, 2006; for a review, see Pugh & Bergin, 2005).

Defining transformative experience

Dewey (1980) suggested that the arts have a unique potential to transform individuals' perceptions of the world, and he linked such transformation with the undergoing of "an" experience: a particularly meaningful type of experience. The qualities of "an" experience are reflected in Dewey's writings on educational experience, including the process of engaging with ideas (Dewey, 1933; Pugh, 2011; Wong et al., 2001). That is, engagement with the ideas contained in the school curriculum can yield a transformative experience similar to that found in the arts. Transformative, in this case, refers specifically to using content ideas in everyday experience to see and value the world in new ways.

In order to translate this general perspective into a researchable construct, Pugh (2002, 2011) defined a transformative experience in terms of three characteristics: motivated use, expansion of perception, and experiential value. *Motivated use* refers to the application of school content in contexts where application is not required, particularly in out-of-school contexts. For example, spontaneously thinking about inertia and choosing to analyze events of motion in everyday life (e.g., car crash, baseball trajectory) in terms of inertia is an example of motivated use. Applying the concept of inertia for a school assignment is not motivated use. The construct of motivated use intersects with research on the role of agency in transfer[1] (Engle, 2006). Motivated use represents the choice to apply learning in a nonconstrained or "free-choice" transfer situation (Pugh & Bergin, 2005). Motivated use also encompasses the constructs of *continuing motivation* (Maehr, 1976) and *school-prompted interest* (Bergin, 1992), which denote a choice to continue learning about a school topic even in the absence of external pressure to do so (e.g., students choosing to learn more about inertia because they found the topic interesting).

Expansion of perception occurs when individuals come to see aspects of the world (e.g., events, objects, issues, themselves) through the lens of the content and perceive deeper layers of meaning. Girod, Rau, and Schepige (2003) referred to this process as "re-seeing." For example, after learning about adaptation in a high school biology class, a student commented, "I now don't just look at [an] animal and say, 'That's cute.' I stop and think a little harder. … [The concept of adaptation] made me look past the animal and made me try to understand more about it" (Pugh, 2002, p. 1128).

Experiential value refers to developing greater value for those aspects of the world re-seen through the lens of the content and, consequently, developing greater value for the science content itself. For example, a middle school student stated that Newton's laws were "fascinating" because they "made me think about stuff that I'm not used to thinking about in that way" (Pugh, 2004, p. 187) and implied that this re-seeing was valuable in that "when two cars crash into each other, I can look at that in a different way, and when I watch a movie I can look at that in a different way. Now I'm going to see things that I'm used to seeing in a different way" (Pugh, 2004, p. 189). Experiential value developed as this student came to appreciate the content for the way it expanded perception of and enriched everyday experiences. Experiential value relates to the constructs of *task value* (Wigfield & Eccles, 1992) and *individual interest* (Hidi & Renninger, 2006; Schiefele, 1991; see Pugh, 2011 for a discussion).

This conception of transformative experience fits within the broader context of research on engagement. Engagement refers to the quality and intensity of student involvement and is a holistic concept encompassing behavioral, cognitive, and affective dimensions of learning (Connell, 1990; Fredricks, Blumenfeld, & Paris, 2004). Transformative experience is similarly a holistic construct with the three characteristics (motivated use, expansion of perception, and experiential value) roughly corresponding to the behavioral, cognitive, and affective dimensions, respectively (Pugh, 2011). The construct of transformative experience is unique in that it places particular emphasis on *engagement that extends beyond the classroom*.

Teaching for transformative experiences

Methods of teaching for transformative experiences were developed and implemented by researchers in prior intervention studies and found to be effective at supporting both learning and transformative experience (Girod et al., 2003; Girod et al., 2010; Pugh, 2002). Based on this work, Pugh and Girod (2007) identified a general framework for fostering transformative experiences, and this framework was used by Pugh et al. (2010b) as the basis for proposing the TTES model. In a college setting, Heddy and colleagues (Heddy & Sinatra, 2013; Heddy, Sinatra, Seli, Taasoobshirazi, & Mukhopadhyay, 2016) found the TTES model to be effective at facilitating transformative experiences, positive emotions, interest, learning, and conceptual change. However, the Pugh et al. (2010b) study involved implementation of the TTES model by a practicing high school biology teacher, and the results were mixed in terms of the depth of the implementation, learning outcomes, and transformative experiences. Consequently, further refinement of the TTES model and investigation of the process of learning to teach for transformative experiences are warranted.

Design principles for the current study

For the current study, we generally adopted the strategies used in Pugh et al. (2010b) as initial design principles upon which specific classroom practices could be developed in collaboration with a teacher (see Table 1). These principles include framing the content as ideas, scaffolding re-seeing, and modeling transformative experiences.

Framing the content as ideas

Increased attention is being paid to how the framing of learning purposes can establish student orientations toward learning and consequently influence learning outcomes (e.g., Engle, Nguyen, & Mendelson, 2011; van de Sande & Greeno, 2010; Watanabe, 1993). Such framing is typically accomplished through metacommunicative signals about the learning situation, including the learning purpose and participation norms (Engle et al., 2011). For example, the discourse a teacher uses to establish the purpose of an activity and the layout of classroom space will help frame the meaning of learning and norms of participation.

In the TTES model, framing is used to establish a perspective of learning as engagement with *ideas* versus learning as the acquisition of *concepts*. In Dewey's (1933) model of reflective thinking, ideas are possibilities (i.e., conditional meanings) that generate anticipation leading individuals to test such ideas in everyday experience. The validity of an idea is determined by "the extent to which it opens up new experiences for a person as he or she interacts with objects and events in the environment" (Prawat, 1998, p. 204). Thus, framing content as ideas is to frame it as possibilities (i.e., possible ways of seeing, experiencing, and understanding the world) that hold the potential for enriching and expanding everyday experience.

Specific classroom strategies for accomplishing such framing include "artistically" crafting dialogues and using metaphors to create anticipation (Pugh et al., 2010b; Pugh & Girod, 2007). Artists craft materials in order to evoke particular experiences. Likewise, teachers can craft discourse in a manner

Table 1. Design model.

Transformative experience	Design principles (from the TTES Model)	Specific classroom strategies
Motivated use Students apply learning in their everyday experience without compulsion.	*Frame content as ideas* Present the content as compelling possibilities. Generate idea-based anticipation. Emphasize the value of the content in everyday experience. Inspires motivated use and supports development of experiential value.	*"Artistically" crafted topic introductions* Use discourse to evoke anticipation and convey the experiential value of the content. Strategy for framing the content as ideas and modeling transformative experiences.
Expansion of perception Students come to "re-see" the world by viewing it through the lens of science content.	*Scaffold re-seeing* Provide guidance and supports that help students see aspects of the everyday world through the lens of science content. Supports expansion of perception.	*Compelling metaphors* Use metaphors that generate anticipation and present the content as compelling possibilities. Strategy for framing the content as ideas.
Experiential value Students gain appreciation for parts of the world that are re-seen and value science content for its affordances in terms of such re-seeing.	*Model transformative experiences* Share personal transformative experiences and express a passion for the content. Inspires motivated use, supports re-seeing, and establishes experiential value.	*Experientially anchored instruction*[a] Identifying and sharing everyday experiences related to the content. Developing case studies out of students' personal experiences. Using these case studies as a basis for the curriculum. Strategy for scaffolding re-seeing and modeling transformative experiences.
		Real-world updates[b] Checking in on real-world phenomena related to the content. Strategy for scaffolding re-seeing.

Note. [a]In year one, a less involved version of this strategy was used. Referred to as "carpet time" by the teacher, it involved teacher and students identify and sharing everyday experiences related to the content. [b]Developed for the year two intervention.
TTES = Teaching for Transformative Experiences in Science.

that presents the content as a possibility, evokes anticipation, and emphasizes its experiential value (Pugh & Girod, 2007). For example, Girod and Wong (2002) used the metaphor "Every rock is a story waiting to be read" as a way of presenting geology content to fourth graders as an idea that generated anticipation and action. Framing can support all three characteristics of a transformative experience but has particular relevance for fostering motivated use (by generating anticipation and orienting students toward the purpose of trying out ideas in everyday experience) and experiential value (because emphasis is placed on the content's experiential value).

Scaffolding re-seeing

Scaffolding has roots in Vygotsky's (1978) work on the zone of proximal development and is a key component of apprenticeship models used to help students appropriate ways of thinking and acting (e.g., Brown, Collins & Duguid, 1989; Palincsar & Brown, 1984; Wood, Bruner, & Ross, 1976). Even when students engage with content as ideas, they may struggle to participate in re-seeing because they lack the cognitive skills to see the world through the lens of the content in a sophisticated way and/or do not recognize opportunities for re-seeing. Scaffolding can be used to support students as they develop cognitive skills and identify out-of-school contexts as appropriate contexts for re-seeing. Out-of-school contexts often differ from the in-school context in that they do not contain salient cues for applying school learning; scaffolding can help students attune to certain real-world cues (e.g., altitude changes as opportunities for thinking about air pressure). Specific scaffolding strategies in the TTES model include such actions as helping students identify everyday objects or events that could be re-seen, coaching students through re-seeing attempts, and providing opportunities for the students to share re-seeing experiences with peers so they can learn from each other (Pugh et al., 2010b). Scaffolding re-seeing supports the expansion of perception.

Modeling transformative experiences

Modeling, in conjunction with scaffolding, can help individuals appropriate cognitive skills (e.g., Palincsar & Brown, 1984) and establish particular values and norms within a community of practice (e.g., Akerson, Cullen, & Hanson, 2009; Brophy, 2008). Modeling of transformative experiences can help students appropriate skills such as re-seeing objects through the lens of particular ideas. It can also convey the value of engaging in re-seeing and help establish such activity as a norm of the classroom. This modeling can take the form of sharing personal experiences of re-seeing the world through the lens of the content and expressing a passion for the content (Pugh & Girod, 2007). In essence, the goal is to show students what it means to live the content. Modeling transformative experiences supports all three characteristics of a transformative experience by inspiring motivated use, providing examples of re-seeing, and conveying information about the experiential value of the content.

Research on teacher change

Given that implementation of any novel instructional model requires change on the part of teachers, it is difficult and unwise to separate the instructional model from teacher change. Teacher change is a constructive process in which teachers make sense of new pedagogy in terms of existing practices and beliefs (Briscoe, 1996; Dwyer, Ringstaff, & Sandholtz, 1991; Hashweh, 2003; Winitzky & Kauchak, 1997). Consequently, they are more apt to understand and implement strategies consistent with existing practices and beliefs (Appleton & Asoko, 1996; Gunel, 2008; Tabachnick & Zeichner, 1999). In addition, change is typically a developmental process in which teachers progress from peripheral changes to fundamental shifts in practice as they reconstruct ideas, beliefs, and understandings. For example, Marzano, Waters, and McNulty (2005) distinguish between first-order (peripheral) and second-order (fundamental) changes. Second-order changes are more difficult and typically emerge over an extended period of time.

These characteristics of teacher change were illustrated in the Pugh et al. (2010b) study. The participating teacher successfully implemented aspects of the TTES model consistent with existing practice and beliefs. However, much of the change was classified as first-order. The TTES strategies generally represented "add-ons" to existing practice rather than fundamental shifts. They were often implemented in the first 10 minutes of class apart from subsequent instructional activities and at a more superficial level. In addition, students were often more engaged in the affective components of activities but fell short of *cognitive* engagement (Blumenfeld, Megendoller & Puro, 1992). Consequently, the current study was conceived as a design-based study in which a recursive pattern of implementation, observation, and reflection could be used to understand and address these challenges by refining the TTES model in a way it might be more centrally implemented.

Current study

The purpose of the current research was to further evaluate the effectiveness of the TTES model when implemented by a practicing teacher and refine specific classroom strategies in response to emerging challenges. The research was designed as a 2-year study. In year one, we worked with a sixth-grade science teacher to implement the TTES model in the context of a 9-week weather unit. We chose not to revise the model in year one to see whether similar challenges arose as in the Pugh et al. (2010b) study. In line with design-based research (e.g., Brown, 1992; Collins et al., 2004; The Design-Based Research Collective, 2003), we analyzed the nature and effectiveness of the implementation of the TTES model and refined strategies in response to challenges identified. In year two, we worked with the teacher to implement the refined strategies in the context of the same weather unit and evaluated the results.

Year one

Context

The participating teacher, whom we will refer to as Hayden, was a sixth-grade earth science teacher with 9 years of experience. The middle school at which Hayden taught was located in a mid-sized town in the West. At the time of the study, about three-fourths of the students at the school were Caucasian and just over 20% were Latino/a. Nearly half (41%) of the students at the school qualified for free or reduced-price lunch.

Hayden described his teaching style as in "some ways traditional and in other ways, nontraditional." He clarified that he typically used a variety of assessments and instructional methods: "I'll do some lecture or modeling, I'll do some exploratory and ask a question and ask the kids to answer it. So I guess it's a varied teaching style." He also explained that he liked a degree of order in the classroom stating, "I set clear expectations and expect that they're followed." Classroom observations confirmed Hayden employed a mix of direct instruction, group work, and individual homework assignments. He typically began a unit section by explaining the topic and probing students' understanding with questions, followed by a group activity (e.g., hands-on experiment, workbook assignment). Observation also confirmed that Hayden maintained order in his classroom by clarifying expectations and criticizing students when they engaged in off-task behavior.

Two of Hayden's four classes were randomly selected to serve as the TTES intervention condition. Hayden worked with the research team to implement the TTES design principles in these classes during a 6-week weather unit; he did not modify his typical instruction in the other two classes, hereafter referred to as the comparison condition. The weather unit covered the topics of air pressure, heat transfer, and the nature of weather events.

Research questions

In this phase of the research, we were interested in two questions:

1. Did the teacher exhibit challenges in implementing the TTES model like those observed in the Pugh et al. (2010b) study? If so, what was the nature of these struggles and how might the model be modified to support future implementation?
2. Compared to the comparison condition, how effective was the intervention at fostering both learning and transformative experience?

Method

Sample

Fifty-three students (55% female; 78% Caucasian, 8% Latino/a, 2% African American, 12% mixed or not specified race/ethnicity) from Hayden's four classes participated in the study.

Intervention

Prior to the weather unit, we explained the design principles of the TTES model (see Table 1) to Hayden and worked with him to modify lessons in line with these principles. Over the course of the 9-week unit, the first author met with Hayden on a weekly basis to discuss the progress of the implementation. During these informal discussions, the two briefly reviewed the week's activities and considered options for upcoming lessons.

In terms of framing the content as ideas, Hayden made efforts to elicit anticipation by artistically crafting some of his topic introductions. For example, he referenced dramatic local weather events (e.g., a tornado, a historic flood) and commented that weather is a wild force that cannot be controlled but can be understood. He sought to create anticipation by proposing to give students the scientific lenses needed to understand weather. He also emphasized experiential value of the content by explaining how it was "really cool" to be able to understand weather events such as strong winds or violent thunderstorm. In addition, Hayden framed the content through the metaphor *weather as recipe*. Hayden explained that, just as dramatically different meals can result from the same basic foods, so dramatically different weather can result from the same basic elements. He introduced the basic elements of the water cycle, air pressure, and heat transfer and he explained that different recipes (i.e., different combinations of these elements) create different weather patterns. Again, he sought to create anticipation by telling students they could come to understand and even predict the weather they experienced in their everyday lives by learning about how the recipe worked.

Scaffolding re-seeing and modeling transformative experience were incorporated in an activity that came to be known as "carpet time." During carpet time, Hayden invited the students to gather on a carpet, where he shared some of his own experiences of seeing the world through the lens of the content (i.e., modeling transformative experience). For example, at the start of an air pressure lesson, Hayden opened a yogurt container. As expected, the yogurt squirted out once the seal was opened. Hayden then said that whenever he opens a yogurt container and the yogurt squirts out like that, he thinks about air pressure. He proceeded to explain how a difference in air pressure between where the yogurt was packaged and where it was opened (the school is at a higher altitude) is responsible for the squirt. He commented that he found it cool to be able to explain why the yogurt does that.

Shifting from modeling his own transformative experience to scaffolding the student's re-seeing, Hayden asked the students to share any examples they had noticed of air pressure in action. The students shared a few examples, such as air pressure making a balloon expand and air pressure being involved when you suck on a straw. Hayden helped the students identify other events that could be re-seen in terms of air pressure and spent time helping the students use air pressure to more deeply understand the events mentioned. He then encouraged the students to look for additional examples of air pressure in action when they went home. In a subsequent carpet time, he gave students the opportunity to share such examples. Other carpet time events involved sharing examples of heat transfer, stories of dramatic weather events, experiences with weather over the holiday break, and observations of weather reports. Carpet time typically lasted about 10 minutes and was conducted at the beginning of class.

In the comparison condition classes, Hayden introduced content with advanced organizers but did not explicitly try to foster anticipation or emphasize its experiential value. Such action was consistent with his prior teaching and reflective of the fact that even exemplary teachers rarely discuss the value and relevance of content to students' everyday lives (Brophy, 2008). He also did not conduct carpet time activities, although application examples were provided. Again, this was representative of his typical instruction.

Data sources

Classroom observations were used to evaluate the nature of the implementation and identify implementation challenges (research question one). To evaluate the effectiveness of the intervention (research question two), we administered pre– and post–transformative experience measures and learning assessments.

Transformative experience measure. Survey measures of transformative experience were adapted from a measure utilized and determined to work well with a similar population in prior research (Koskey, Stewart, Pugh, & Linnenbrink-Garcia, 2008; Pugh et al., 2010a) and were administered 1 week prior to the weather unit (pre-measure) and immediately following the unit (post-measure). The measures contained items targeting the three qualities of a transformative experience: motivated use, expansion of perception, and experiential value (see Table 2) and were rated on a 4-point scale consisting of *strongly disagree, disagree, agree*, and *strongly agree* options. In addition, the surveys were based on the Pugh et al. (2010a) premise that transformative experience exists as a continuum ranging from in-school to out-of-school engagement, with out-of-school engagement representing a deeper level of engagement. Hence, items targeting students' engagement in class were included to represent the lower end of the transformative experience continuum. For example, the post-measure item "During science class, I thought about weather in terms of the science ideas we learned" targeted in-class expansion of perception, whereas the item "I think about the weather I experience differently now that I have learned these science ideas" targeted a deeper level of out-of-school expansion of perception. The in-school and out-of-school items are not opposed to one another, but rather represent different levels of transformative engagement. The pre-measure (20 items) assessed the degree to which students reported undergoing transformative experiences in science class prior to the intervention, and the post-measures (24 items) assessed the degree to which students underwent transformative experiences specific to weather content during the weather unit (see Table 2).

Table 2. Sample items from the transformative experience measures.

Measure	Item
Pre-measure	
Motivated use	I used the science ideas we learned in class even when I didn't have to.
Expansion of perception	I can't help but see the world in terms of the science ideas we learned.
Experiential value	The science ideas we learned in class made my out-of-school experience more meaningful.
Post-measure	
Motivated use	I used the weather, air pressure, and/or heat transfer ideas we learned in class even when I didn't have to.
Expansion of perception	I can't help but see weather and air pressure in terms of the science ideas we learned.
Experiential value	The weather, air pressure, and/or heat transfer ideas we learned in class make my out-of-school experience more meaningful.

Rasch analysis (Rasch, 1980) was used to evaluate the measures and develop composite scores using WINSTEPS software (Linacre, 2006). Rasch analysis is a valuable tool for measuring complex constructs like transformative experience because it provides information on whether the different characteristics hold together and function as a unidimensional construct (Bond & Fox, 2001). In addition, the Rasch model provides rich information about participant performance and the nature of the construct being measured (Bond & Fox, 2001). Instead of treating all items equally and computing an overall score (e.g., a mean of 3.1 on 4-point scale), the Rasch model places items in a hierarchy ranging from those easiest to most difficult to agree to; any student's individual score provides information about which items that participant was likely and unlikely to agree to.

We first conducted Rasch analysis on the year one data and used these Rasch scores for evaluating potential differences between conditions. After year two was complete, we pooled the data from both years so there would be equivalence in Rasch scores and reran the year one analyses. We report the measure functioning and intervention results for the pooled data[2].

Following Wright and Linacre (1994), we used infit MNSQ > 1.4 as a cutoff for misfitting items (i.e., items not holding together with the others in the Rasch model). One item from the pre-measure and one item from the post-measure were dropped due to misfit. The other items fit the model indicating unidimensionality of the construct. The final measures had acceptable person separations (pre $= 2.61$, post $= 3.19$) and item separations (pre $= 6.56$, post $= 7.77$), indicating that the measures distinguished among people and among different levels of transformative engagement along the continuum. The final measures also had acceptable person reliability (pre $= .87$, post $= .91$) and item reliability (pre and post $= .98$), indicating replicability of the ordering of persons and items along the continuum for similar samples.

Learning assessments. Pre-test and post-test learning assessments were developed in collaboration with Hayden. The post-test was adapted from Hayden's existing assessment by selecting and modifying application-oriented multiple-choice items and adding open-response items targeting application in real-world situations. Select items from the post-test were altered for inclusion in the pre-test. The pre-test contained 12 items (6 multiple choice and 6 open-response)[3] and the post-test contained 20 items (13 multiple choice and 7 open-response[4]; see Table 3). Due to the application focus of the items, both assessments were considered to be difficult assessments addressing deeper levels of learning (Bruer, 1993), particularly in the case of the post-test. The pre-test was used as a covariate in the analysis and was not intended to be equivalent to the post-test. Open-response items were scored by two independent raters. Intraclass correlation coefficients were .949 for the pre-test and .975 for the post-test. Disagreements in ratings were resolved through discussion to produce final scores used for analyses.

Classroom observations. Three observations of Hayden's teaching were made prior to the intervention to gain an understanding of Hayden's typical teaching style and the instructional context. During the intervention, one member of the research team observed classes in the experimental condition an average of one to two times per week and recorded field notes, including Hayden's actions and the students' responses.

Table 3. Sample items from the post-test learning assessment.

Multiple-choice item	A warm, moist mass of air moves eastward and meets up with a cold mass of air. What will happen where these two air masses meet? A. The warm air mass will start to move over the cold air mass. B. The warm air mass will start to move under the cold air mass. C. The air masses will mix together and one won't move over or under the other. D. The air masses will stay apart and one won't move over or under the other.
Open-response item	A group of girl scouts went hiking in Rocky Mountain National Park. They noticed that it was harder to breath when hiking in the mountains than when hiking in [hometown]. During the hike, one girl opened a tube of suntan lotion that she bought in [hometown]. When she opened it, a small squirt of air and lotion shot out. Why did the girls have a hard time breathing? Why did the air and lotion squirt out of the tube?

Results

Successes and challenges in implementing the TTES model

Observations of the implementation revealed that although Hayden successfully implemented a number of aspects of the TTES model, such implementations were often isolated from other class activities. For instance, themes presented in the driving metaphor and artistically crafted content introductions were not followed up on in subsequent activities. In addition, the carpet time activities generally functioned as a break from typical schoolwork rather than as an activity providing context and meaning to the schoolwork. For instance, after the carpet time in which students shared experiences with air pressure in everyday experience, the students returned to their desks and were given workbook assignments to complete. No connection was made between the carpet time discussion and the assignments.

A second challenge was that students regularly responded to TTES activities with low cognitive depth. During carpet time activities, students commonly shared affectively charged examples that lacked deep connections to core content. For example, when asked to share weather experiences, many students enthusiastically shared stories ranging from hurricane Katrina to getting snowed in. Hayden prompted the students to consider the combination of elements that led to these weather events, but students remained primarily engaged with affective components of the stories. For instance, they talked about how cool it would be to see a hurricane and how awesome it would be to tunnel out their front doors through snow. Few stories were deeply connected to the unit content.

Effectiveness of the intervention

Table 4 lists the descriptive statistics for the transformative experience measures and learning assessments. To clarify the meaning of the transformative experience Rasch scores, Figure 1 provides an item map of the post-measure results. Rasch analysis orders items in terms of difficulty and provides probabilistic data on the likelihood of students endorsing particular items (Bond & Fox, 2001). Students are likely to endorse items located below their Rasch score, not endorse items located above, and have a 50/50 probability of endorsing items at the same level. In terms of the current study, students in both conditions are predicted, on average, to have endorsed most of the items targeting in-class engagement but not many of those targeting out-of-school engagement. However, the TTES condition mean was higher and students in this condition are, on average, predicted to have an even chance of endorsing some of the explicit out-of-school engagement items.

Performance on the pre-test was low for students in both conditions, as expected. On the post-test, performance in the control condition was relatively low, indicating that students were still struggling to apply content in real-world situations. Performance in the TTES condition was higher, indicating that students could apply content in real-world situations but still struggled to apply it fully and in all situations.

To test for statistically significant differences between the comparison and TTES conditions on the transformative experience post-measure, we conducted an analysis of covariance (ANCOVA)[5]with the transformative experience pre-measure as the covariate. We found a significant pre-measure by condition interaction with a medium effect size[6] ($F(1, 48) = 4.03$, $p = .050$, $\eta_p^2 = .08$), suggesting that the

Table 4. Year one descriptive statistics.

	TTES		Control	
Outcome	*n*	*M (SD)*	*n*	*M (SD)*
TE measure				
Pre-measure[a]	30	.50 (.91)	23	.24 (.98)
Post-measure[a]	30	.33 (.96)	21	.06 (.71)
Learning				
Multiple-choice items				
Pre-test[b]	30	3.9 (2.23)	23	4.0 (1.88)
Post-test[c]	30	15.3 (4.57)	23	11.3 (3.07)
Open-response items				
Pre-test[d]	30	4.1 (1.96)	23	3.3 (1.46)
Post-test[e]	30	5.0 (3.24)	23	2.6 (1.44)

Note. TE = transformative experience; TTES = Teaching for Transformative Experiences in Science.
[a]Rasch score < –.5 = *in-class engagement only*; 0 = *somewhat transformative*; > .75 = *significantly transformative*.
[b]Points possible = 9.
[c]Points possible = 23.
[d]Points possible = 12.
[e]Points possible = 14.

effectiveness of the intervention was dependent on reported levels of prior transformative experience in the science class. To make sense of this interaction, we created high (top third[7]) and low (bottom third) prior transformative experience groups and graphed these by condition (see Figure 2A). The histogram suggests the TTES intervention was more effective for those with high levels of prior transformative experience in the class and not at all effective for those with low levels of prior transformative experience.

An ANCOVA[8] was used to test for statistically significant differences on the multiple-choice post-test items with the multiple-choice pre-test items as the covariate. A statistically significant difference was found with students in the TTES condition achieving greater learning than students in the comparison condition ($F(1, 50) = 16.01$, $p < .001$, $\eta_p^2 = .24$). An ANCOVA[9] was also used to test for statistically significant differences on the open-response post-test items with the open-response pre-test items as the covariate. We found a significant pre-test by condition interaction ($F(1, 49) = 8.09$, $p = .006$, $\eta_p^2 = .14$), suggesting that the effectiveness of the intervention was dependent on prior knowledge. To makes sense of this interaction, we created high and low groups based on open-response pre-test scores and plotted group scores by condition (see Figure 2B). We were unable to create these groups based on thirds due to the limited number of score levels. So we approximated thirds by creating a low group from those who scored one to two ($n = 13$) and a high group from those who scored five to nine ($n = 16$). Similar to the transformative experience results, the TTES intervention was effective for those with high pre-test open-response performance but not effective for those with low pre-test open-response performance.

Discussion

The results from year one were similar to those found in the Pugh et al. (2010b) study. The teacher's implementation of the TTES model was successful in a number of ways. However, the TTES strategies were often implemented in isolation from existing practices, consistent with literature regarding change in teacher practice. It is difficult for teachers to immediately implement fundamental changes; it is typically a more gradual process (Tyack & Cuban, 1995; Marzano et al., 2005). In addition, student engagement during TTES activities often reflected affective engagement rather than cognitive engagement (Blumenfeld et al., 1992).

Given the combination of successes and challenges in implementing the TTES model, it is not surprising that the results were mixed in terms of the effectiveness of the model. The positive transformative experience effects were limited to students scoring higher on the pre-survey. These students may

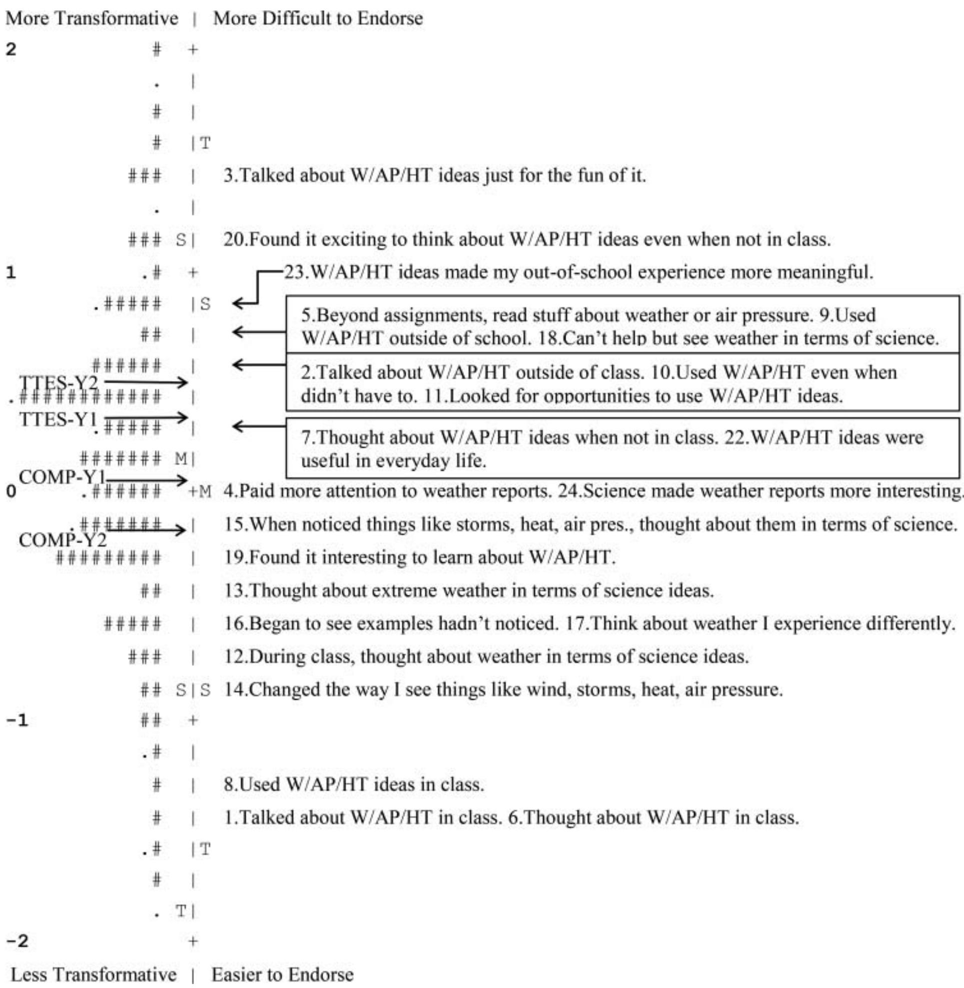

Figure 1. Transformative experience measure item map (years one and two combined). Note: Numbers along left edge represent Rasch scores. Students are represented on the left side ordered by least transformative (bottom) to most transformative (top). Each '#' = 2 students and each '.' = 1 student. $N = 202$. Eight students scored above 2 and six students scored below −2. Items are represented by an abbreviated statement on the right side ordered by easiest to endorse (bottom) to hardest to endorse (top). Full items are available in online supplementary materials. W/AP/HT = weather/air pressure/heat transfer; M = mean; S = one standard deviation from the mean; T = two standard deviations from the mean; TTES-Y1 = intervention condition year 1 mean; TTES-Y2 = intervention condition year 2 mean; COMP-Y1 = comparison condition year 1 mean; COMP-Y2 = comparison condition year 2 mean. The Rasch model generally predicts that students will endorse items located below them on the map, not endorse items located above, and have a 50/50 probability of endorsing items at the same level.

have had a low threshold for transformative experience and the TTES intervention was able to help them cross this threshold. A similar explanation may apply to the open-response results in which a parallel aptitude–treatment interaction was found. It is also possible that these two results are related given the association between transformative experience and deep learning found in prior research (e.g., Pugh et al., 2010a).

Overall, the data support a greater effect on learning than transformative experience, as the multiple-choice results reflected greater learning in the TTES condition compared to the comparison condition, regardless of student prior knowledge. These findings can be interpreted in several ways. One possibility is that the TTES model fostered learning independent of engagement in transformative experience. Another possibility is that the measure of transformative experience is less sensitive than the learning measure. Assessing transformative experience is challenging, as it requires asking students to reflect on their experience with the content in everyday life and such reflections are unlikely to be

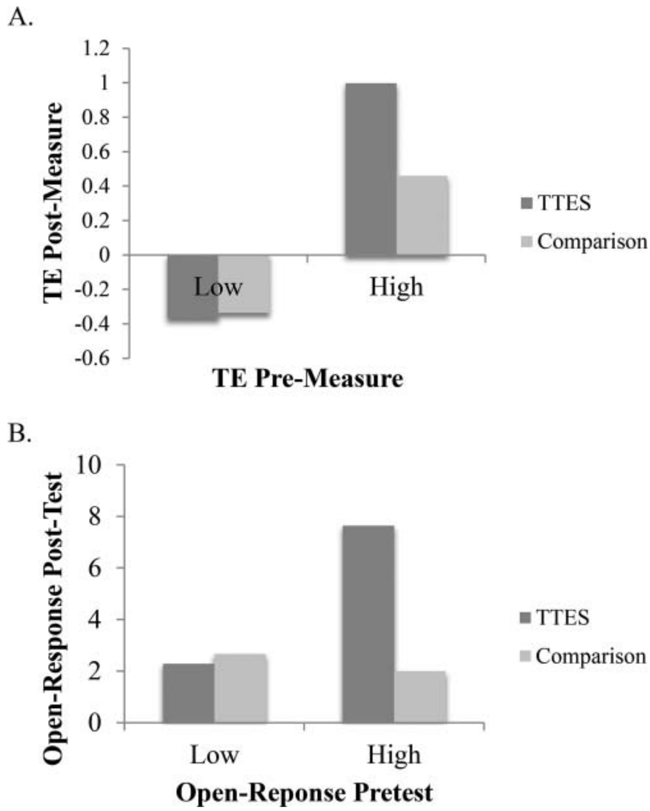

Figure 2. Aptitude by treatment interactions for year one data. Note: A. Low = bottom third; high = top third. B. Low = score 1–2; high = score 5–9.

fully accurate (i.e., students may struggle to bring to mind experiences of interacting with content in everyday experience) and may be prone to positive response bias. Consequently, the transformative experience measure may be less sensitive to real differences.

Taken together, the results suggest that modifications to the TTES model were needed to facilitate implementation and support the transformative experiences and deep learning for all students. Accordingly, aligned with the model of design-based research (e.g., Brown, 1992; Collins et al., 2004; The Design-Based Research Collective, 2003), we collaborated with Hayden to develop and refine TTES strategies.

Year two

The purpose of the year two study was to investigate the implementation and effectiveness of the revised TTES model in relation to the same weather unit. The design was modified from year one to accommodate Hayden's requests. He perceived the TTES intervention to be beneficial and believed it would be difficult and unethical for him to use TTES strategies in some classes but not others. Consequently, we recruited the other earth science teacher at the school and used his classes as a comparison condition for considering the effectiveness of the TTES instruction. This teacher's pedagogy reflected a common approach to science instruction and will hereafter be referred to as the standard instruction condition. The implementation of the revised TTES model in Hayden's classes will be referred to as the TTES condition.

The following research questions guided the research:

1. Are there statistically significant differences between the TTES and standard instruction conditions on measures of transformative experience?

2. Are there statistically significant differences between the TTES and standard instruction conditions on measures of learning?

We hypothesized that students in the TTES condition would score higher on measures of transformative experience and learning.

Method

Sample

The total sample consisted of 158 sixth-grade earth science students (49.7% female; 53.3% Caucasian, 16.0% Latino/a, 30.7% mixed or other race/ethnicity). The TTES condition consisted of 76 students (54.1% female; 56.2% Caucasian, 12.3% Latino/a, 31.5% mixed or other race/ethnicity) and the standard instruction condition consisted of 82 students (45.5% female; 50.6% Caucasian, 19.5% Latino/a, 29.9% mixed or other race/ethnicity). There were no statistically significant differences between conditions in terms of gender and race/ethnicity.

Procedure

Prior to the weather unit, the two teachers aligned their curricula so they would be teaching the same content over the same time period. Instructional time was approximately 9 weeks for both teachers. The transformative experience pre-measure and pre-test learning assessment were administered a week prior to the unit. The post-test learning assessment was administered at the conclusion of the unit as part of the teachers' unit assessment. The transformative experience post-measure was also administered at the conclusion of the unit and interviews were conducted with a sample of students from both conditions the following week.

Similar to year one, Hayden and the first author reviewed unit lesson plans and discussed options for implementing the revised TTES model. Discussions primarily centered on ways of implementing two refined strategies, experientially anchored instruction and real-world updates, which are explained below. The first author observed classes weekly, and five class sessions in the TTES condition were filmed. Segments of the filming were transcribed and used to help describe the nature of the intervention.

TTES condition

In year two, Hayden again focused on artistically crafting topic introductions and using a compelling metaphor, while implementing two additional strategies focused on scaffolding re-seeing and modeling transformative experience (see Table 1). The additional strategies were designed to integrate the TTES model with other classroom practices and support deeper cognitive engagement.

Artistic crafting and compelling metaphors. As in year one, Hayden sought to frame content as ideas, evoking anticipation and emphasizing the experiential value of the content, by getting students to consider the potential relevance of the content and emphasizing such relevance as the purpose for learning the content. For instance, Hayden introduced the weather unit, commenting, "we don't really think about how weather impacts us. Hopefully in this unit we will start to realize how weather really impacts your life." He then shared an experience of being in a tornado and showed a picture of tornado damage that occurred in a town near the school a year earlier. Most students remembered this tornado and some even experienced it. Hayden allowed them to share and prompted other students to share wild weather experiences they had prepared prior to class. Students eagerly shared stories of blizzards, lightening hitting a house, Hurricane Katrina, and others.

Hayden again introduced the *weather as recipe* metaphor as with year one, but elaborated. "There's just a couple of ingredients, and depending on how you put those ingredients together, you could get a beautiful day like we have today, sunny and almost 70 degrees in February. Change those ingredients a little bit, and we get tornados and blizzards." He then elicited ideas from students about what factors might be considered "ingredients" and commented:

> Over the next several weeks, we're going to be thinking like scientists … so the next time you have that memorable weather experience, you can sit down, watch the weather, and say, "Hey, there might be a lot of evaporation or condensation going on." Or on a nice day like today, "I wonder what the air pressure is doing?" And that's what's going to be so cool, is that we're going to be able to do that. We're going to learn about these ingredients.

Hayden similarly emphasized the relevance of the content in everyday experience and sought to evoke anticipation when introducing the topics of air pressure and heat transfer.

Experientially anchored instruction. The Cognition and Technology Group at Vanderbilt (1992) used the term "anchored instruction" to refer to instruction that was "anchored" (i.e., situated) in authentic problem-solving environments. *Experientially* anchored instruction involves anchoring instruction in problem-solving environments derived from the students' own experiences. This strategy was coconstructed with Hayden in an attempt to better integrate the year one carpet time activity into Hayden's pedagogy and support greater cognitive depth. Below we describe one experientially anchored instruction episode Hayden used to ground a study of air pressure in students' personal experiences with air pressure.

Hayden began with a carpet time activity similar to that used in year one, having students record observations of air pressure in their everyday lives and bring their write-ups to class to share. One student talked about opening a bottle of wine, "It was closed tightly then when I opened it, it made a popping sound and, and then all the air escapes, the air pressure escapes." Other representative examples included a sick sister having trouble with her ears popping, labels on soda cans warning "contents under pressure," and an infant niece burping. The session ended with a student talking about smoke going up her chimney, "The air pressure in the fireplace at my house has to escape into the air or it will come into our house."

To press for cognitive depth and integrate students' experiences into the curriculum, Hayden and the first author developed case studies out of the student experiences (see Table 5). Student pairs then researched different case studies, completed a report and poster, and gave a presentation to the class. Researching these case studies allowed students to examine their experiences with greater cognitive depth compared to year one, when they shared experiences but struggled to discuss them in terms of science content. In addition, researching the case studies integrated the TTES strategies into the curriculum.

Hayden did a similar experientially anchored instruction exercise during the weather unit, developing students' own wild weather experiences into case studies that the students then investigated. See Table 5 for an example of a case study compiled from students' experiences with hailstorms. Experiential instruction was not used to teach heat transfer because Hayden felt that three case study projects would be too much for students. However, he did implement activities similar to the carpet time activities used in year one when teaching heat transfer.

Real-world updates. The real-world updates strategy was added as an attempt to develop re-seeing into a habit. Conducting real-world updates involved "checking in" on a real-world phenomenon related to the content at the start of class. For the air pressure topic, barometric pressure was used. Hayden had the students construct barometers and check on these for one week while considering connections between barometric pressure and the weather, thus encouraging them to re-see both barometric pressure reports and weather events. For example, students noted that their barometers had gone up the first day, then had gone down or stayed the same the second day. Hayden asked, "What do you think might have caused that?" A student responded, "The weather yesterday night, 'cause it was really snowy. Then today it was not as cold as yesterday and it was kind of sunny." Hayden then led students in a short discussion of how air pressure might relate to temperature and weather.

For the heat transfer topic, the students used an Internet site to look up temperatures around the local area and considered the connection to the heat transfer properties of environmental features. For the topic of weather events, Hayden had the students check an online weather report about three times a week. They used the in-class computer to pull up a current weather report map and the class spent

Table 5. Sample case studies used for experientially anchored instruction.

Up in Smoke
One student observed that her fireplace (like all fireplaces) has a chimney for the smoke to up. Why does the smoke go up the chimney (as long as the flue is open) instead of just staying where it is or going out into the room? Does air pressure have anything to do with it?
Windy Doorways
As one student pointed out, there is often a wind blowing out the doors of the school. As soon as you open the doors, you get hit by it. But once you're inside, there's no more wind. What is going on? Why is there this mysterious wind in the doorway?
Popping Ears
A couple of students mentioned that their ears popped either going up to the mountains or coming back down. One student noticed this happening while driving to the ski resort and another noticed it happening when coming back from [mountain town]. What's going on? Why do our ears pop?
Watch Out for That Hail!
It was another hot sunny day. Melanie and Kira were sitting at home. Alonso was flying a kite at the sand dunes, Natalia was going to church, Carl was getting off the bus, Evan was standing outside Dominos, and Beth was watching TV. Then, out of nowhere, the sky got all grey and it started hailing. Natalia described it this way, "The hail started out the size of tic-tacs and then it grew to the size of popcorn." She watched with interest as the popcorn-sized hail dented her pastor's car. Melanie and Kira described the hail as the size of marbles. Evan thought it was the size of golf balls. Alonso didn't worry about what size it was, he just ran for cover. Carl did likewise. He put his backpack over his head and ran for home. Beth did the opposite. She looked out the window, said, "Hey, it's snowing. Let's go play in it," and ran outside. It didn't take her long to figure out the difference between snow and hail, and she was quickly back in the house.
What is the recipe that makes this weather pattern?
What is the cause of hail? Why is some hail larger and some smaller? Why do hailstorms often occur in the afternoon on warm summer days? Why do hailstorms often occur in the mountains?

Note. Names have been changed in the hailstorm case study.

about 5 minutes discussing how they could re-see the weather map in terms of unit content. Hayden regularly prompted them to "decode the recipe" that was causing the predicted weather.

Standard instruction condition

The teacher in the standard instruction condition had 2 years of prior teaching experience. He possessed a degree in middle school education with a second major in environmental and earth science and considered sixth-grade earth science his "ideal position."

To understand the teacher's pedagogical beliefs and practices, we conducted an interview and observed his teaching. The teacher described his style as "hands-on," stating, "I guess that I'm very hands-on. I like doing a lot of things hands-on. I don't like teaching by the books. I think that's how I learned, so that's not how I like teaching. I think that a kid can learn so much more from experiencing it than from reading about it." In addition, he explained that he liked to connect to students' experience and build on their existing ideas. In terms of structure, the teacher explained that he would typically begin class with a review and explanation of a principle. The length of the explanation depended on the novelty and complexity of the principle. Students then worked in groups to complete an activity or experiment. For the weather unit, he used FOSS kits (http://www.lhsfoss.org) for activities and designed some of his own. Occasionally he had students engage in individual seatwork.

We observed the teacher's classroom twice before the weather unit and once during the unit. Our observations aligned with his descriptions. The classes began with a brief review and then a session of direct instruction accompanied by question and answer. Students sat in groups at tables, and most appeared comfortable asking questions and sharing comments. The teacher joked occasionally with students and appeared to have good rapport with the class. After the direct instruction sessions, students were given an inquiry-type activity to work on in their groups. During this time, the teacher circulated around the room checking in with groups, answering questions, and keeping individuals on task.

We considered this pedagogical activity to be reflective of standard practice because science instruction at the middle-school level in the United States typically involves a combination of teacher explanation, whole-class discussion, and engagement in hands-on/laboratory activity (Horizon Research, 2013). Moreover, the FOSS kit activities are reflective of the current emphases on providing inquiry opportunities, interaction with laboratory equipment and technology, and focus on core science content (e.g., American Association for the Advancement of Science, 1993; National Research Council, 1996; 2000). In order to reduce potential bias, the comparison teacher was not informed of the purpose of the study and was simply asked to teach the unit using his typical methods.

Data sources

The pre- and post-measures of transformative experiences from year one were used in year two. Focus group interviews were added as an additional data source for assessing transformative experience. These interviews were added to provide triangulation of data and an additional means of describing engagement related to transformative experience. New pre– and post–learning assessments were developed to accommodate the second teacher.

Focus group interviews

Interviews were conducted at the conclusion of the unit in focus groups of two or three students. In the TTES condition, nine students were randomly selected from each of the four classes for a total of 36 interviewees. Only 29 students from the four standard instruction classes received consent from parents to participate in the interviews and assented to participate themselves[10]; thus, we interviewed all 29 students. Within each condition, no statistically significant differences were found on the post-measure of transformative experience between those interviewed and those not interviewed, suggesting the samples were representative (Standard Instruction: $t(99) = -.154$, $p = .878$; TTES: $t(99) = -.354$, $p = .724$).

Structured interviews targeted the three characteristics of transformative experience (motivated use, expansion of perception, and experiential value) relative to each of the main content topics (air pressure, heat transfer, and weather events). Each student was prompted to clarify responses and provide examples or to respond to the questions if he or she did not provide an initial response (refer to Appendix A for an interview guide).

Individual student responses were coded in terms of expressed levels of the three characteristics of transformative experience for each of the three topics. An initial version of the coding scheme was developed and used by two researchers to code the responses of five students. Codes were compared and coding criteria were clarified for categories in which there was disagreement. One of the original raters and a rater blind to condition then used the refined coding scheme to independently code all interviews. Students received 0 to 3 points for each of the three transformative experience characteristics relative to each of the three content areas; scores were summed such that total scores ranged from 0 to 9 per content area. The coding scheme and sample responses are provided in Appendix B. Intraclass correlation coefficients, measuring the correlation between raters' scores, were equal to or greater than .938 for each of the three characteristics. Disagreements in rater scores were resolved through discussion.

Learning assessments

Learning assessments were developed in collaboration with both teachers based on their aligned curriculums. The pre-test contained 16 multiple-choice items and three open-response items.[11] The post-test contained 20 multiple-choice items and seven open-response items.[12] As in year one, the assessments focused on application of learning and were intended to be difficult assessments addressing deeper learning, although recall-level items were included in the pre-test to avoid a floor effect. Both teachers administered the post-test as a unit assessment.

Independent raters scored each open-response item using a predetermined rubric. Interrater reliability, as the correlation between raters' scores, was low for three of the items on the post-test. Consequently, the coding rubric was modified and these items were rescored. Final intraclass correlation coefficients were greater than .90 for each individual item. The intraclass correlation coefficient for total open-response scores was .939 for the pre-test and .991 for the post-test. Disagreements were resolved through discussion.

Results

Descriptive statistics

Table 6 presents the descriptive statistics for the transformative experience measures and learning assessments. Figure 1 illustrates the distribution of students and condition means relative to the transformative experiences items. On average, students in the standard instruction condition were predicted by the Rasch model to have endorsed most of the in-class engagement items but none of those explicitly focusing on out-of-school engagement. In contrast, students in the TTES condition, on average, were predicted to have endorsed or been as likely as not to have endorsed a number of the explicit out-of-school engagement items. The average interview scores were also higher for students in the TTES condition, and a qualitative description of these interview scores is provide below.

In terms of learning, performance on the pre-test was relatively low for both conditions, as expected. Mirroring the year one results, performance on the post-test was still relatively low due to the challenging nature of the assessment and particularly the open-response items, but the average level of performance in the TTES condition was higher.

Transformative experience measure

To compare conditions in terms of the level of transformative experience reported on the post-measure, we conducted an ANCOVA[13] with the pre-measure as the covariate. We found a statistically significant difference and medium effect size, with the TTES condition scoring higher on the post-measure ($F(1, 147) = 8.70$, $p = .004$, $\eta_p^2 = .06$). Unlike in year one, there was no interaction between the transformative experience pre-measure and the condition. The TTES condition in year two showed a unique pattern in that the post-measure mean Rasch score was higher than the pre-measure mean Rasch score (Figure 3).

Interviews

We used a multivariate analysis of covariance (MANCOVA)[14] with the transformative experience pre-measure as a covariate to compare conditions in terms of coded interview scores for the three unit topics (air pressure, heat transfer, and weather events). The MANCOVA was statistically significant ($F(3, 59) = 3.35$, $p = .025$, $\eta_p^2 = .15$), indicating that the conditions differed on the three interview scores as a group, with interviewees from the TTES condition reporting greater levels of transformative experience. The effect size was large. Follow-up ANCOVAs[15] revealed that the conditions differed significantly in terms of levels of transformative experience in relation to the topics of air pressure ($F(1, 61) = 8.08$, $p = .006$, $\eta_p^2 = .12$) and weather events ($F(1, 61) = 4.41$, $p = .040$, $\eta_p^2 = .07$), but not heat transfer ($F(1, 61) = 0.70$, $p = .407$, $\eta_p^2 = .01$). The effect sizes were relatively large and medium for the air pressure and weather events results, respectively.

This difference in transformative experience between the standard instruction and TTES conditions is illustrated qualitatively in students' interview responses. Another publication (Pugh, Bergstrom, & Spencer, under review) provides a more complete account of these interviews. Here, we present an account of typical responses for each condition; that is, responses reflecting the average score for each condition. Overall, students in the standard instruction condition struggled more to provide valid and detailed examples of how they engaged in the characteristics of a transformative experience, and few provided multiple examples or enthusiastic endorsements. The typical student in the standard instruction condition reported applying concepts in their everyday life (motivated use) but provided no or limited examples or explanations, such as the student who observed "I'll … just look at the clouds and I usually don't do that," or the student who expressed thinking about air pressure in everyday life "sometimes at baseball practice," but when prompted for further explanation said, "I don't know. I just thought of it. I don't remember." Similarly, when asked whether they thought about air pressure differently following the unit than they had prior to the unit beginning (expansion of perception), a student from the standard instruction condition replied, "A little bit. [Interviewer prompted student for an example] Like when I see a storm

Table 6. Year two descriptive statistics.

	TTES		Standard Instruction	
Outcome	*n*	*M (SD)*	*n*	*M (SD)*
TE measure				
Pre-measure[a]	74	.27 (0.88)	81	.03 (0.94)
Post-measure[a]	71	.48 (1.16)	80	−.17 (1.13)
TE interview score				
Air pressure[b]	35	4.74 (2.77)	29	3.00 (1.89)
Heat transfer[b]	35	3.94 (2.73)	29	3.38 (2.32)
Weather[b]	35	5.71 (2.73)	29	4.41 (2.03)
Learning assessment				
Multiple choice	76	19.3 (4.70)	81	17.5 (4.76)
Pre-test[c]				
Post-test[d]	69	29.7 (6.19)	77	26.1 (6.77)
Open response				
Pre-test[e]	76	1.4 (1.10)	80	1.1 (1.11)
Post-test[f]	67	7.0 (3.75)	77	3.4 (2.48)

Note. TE = transformative experience; TTES = Teaching for Transformative Experiences in Science.
[a]Rasch score < −.5 = *in-class engagement only*; 0 = *somewhat transformative*; > .75 = *significantly transformative*.
[b]Total possible = 9.
[c]Total possible = 32.
[d]Total possible = 40.
[e]Total possible = 6.
[f]Total possible = 19.

coming, I think about a high pressure front. Then I switch back to regular thoughts." Along this trend, the typical student in the standard instruction condition agreed that content made life more interesting or exciting and found the ideas useful (experiential value), but again provided limited examples and explanations, such as the student who said that knowing about heat transfer made him "A little bit" more interested in how some things work. When prompted for an example, he replied, "I'm not really sure. Just a little bit exciting."

Comparatively, the typical student from the TTES condition not only endorsed the characteristic but offered explanations and examples with fewer prompts from the interviewer and often in greater detail. For instance, one student affirmed, "I know when it's windy I think about it going from high-to-low or from low-to-high … so that's when I think about air pressure a lot." Another volunteered a positive and enthusiastic:

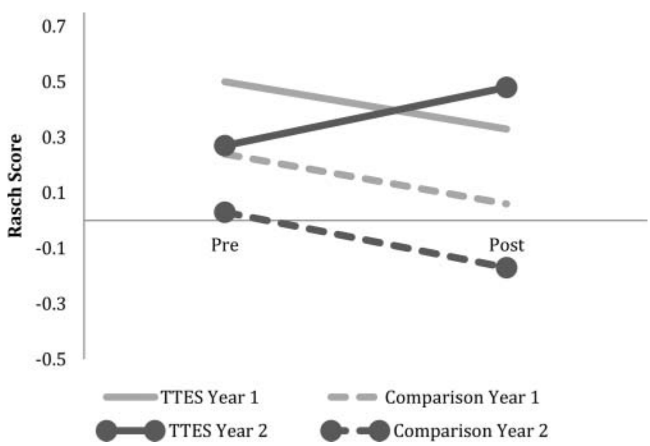

Figure 3. Performance on the transformative experience measure by study and condition. Note: TTES Year 1 = intervention condition year 1; TTES Year 2 = intervention condition year 2; Comparison Year 1 = comparison condition year 1; Comparison Year 2 = comparison (i.e., standard instruction) condition year 2.

> Yes, 'cause when I was driving in the car after the concert, I saw a bunch of clouds, and I was telling my parents, "Oh, that's a cumulonimbus cloud … it's gonna' rain!" … And then a few weeks after we did the weather charts and the cold fronts, I was watching the weather with my parents and stuff, and I saw the blue line with the squares on it, and I'm like, "Oh, there's gonna' be a cold front soon," and then I saw the high and low pressure between Colorado, and I said, "it's gonna' be windy, so prepare yourself."

Students in the TTES condition also more frequently offered at least moderately more detailed examples and explanations of how their perception had changed, such as:

> Before it didn't really matter to me as much as, like, 'cause I just thought of it like it's gonna be hot, cold, rain or snow, I never really thought about it as complex and how many things need to happen before it can actually do the things that happen like snow. And that's mostly what I think about now, I think about it more detailed.

This student's observation also highlights a sense of increased understanding in conjunction with increased awareness of the complexities of those concepts.

Finally, students in the TTES condition more commonly gave enthusiastic endorsements of experiential value, noting, for example, that learning about heat transfer did make life more interesting or exciting because "it does make you feel smarter, and that's pretty cool. Um, and it did when we learned about the sun. So that really fascinates me, and it's really cool." Related to learning about air pressure, another student reported, "I found it more exciting 'cause I know what happens when I leave the lid on my water bottle when we go up to the mountains; I know what happens." Even the student who found no utility value in learning about weather because "I don't want to be a meteorologist or a weather person … it's a little boring since I don't want to have a future in weather" nonetheless gained increased interest: "I just think it's kind of interesting to understand now what different types of things form different types of weather."

Learning assessment

We used an ANCOVA[16] to compare conditions in terms of the post-test multiple-choice items using the pre-test multiple-choice items as a covariate. A statistically significant difference was found, with students in the TTES condition demonstrating higher performance than students in the standard instruction condition ($F(1, 142) = 5.97$, $p = .016$, $\eta_p^2 = .04$). We also used an ANCOVA[17] to compare conditions in terms of the post-test open-response items with the pre-test open-response items as the covariate. Again a statistically significant difference was found with students in the TTES condition demonstrating greater learning ($F(1, 139) = 37.84$, $p < .001$, $\eta_p^2 = .21$). The effect sizes were small to medium for the multiple-choice items and large for the open-response items. Unlike in year one, there was not an aptitude–treatment interaction.

Discussion

The revisions to the TTES model facilitated a more substantial implementation and the results were in line with our hypotheses. In comparison to standard instruction, the revised TTES model was found to be more effective at fostering transformative experiences and learning. In the TTES condition, students on average displayed a level of engagement that can be characterized as approaching transformative experience. That is, they were about as likely as not to endorse most of the transformative experience measure items indicative of out-of-school engagement. In addition, interviewees endorsed the three characteristics of transformative experience and generally were able to provide valid examples or explanations of these characteristics, although more so for the topic of weather and less so for the topic of heat transfer. In contrast, students in the standard instruction condition were unlikely to endorse items indicative of out-of-school engagement on the transformative experience post-measure and, although interviewees endorsed the characteristics of transformative experience, they were generally unable to provide valid examples or explanations.

Results for the post-test learning assessment mirror the transformative experience results. Students in the TTES condition displayed greater learning and this difference was more pronounced for the open-response items, which required more extensive real-world application of content and reflected deeper learning. Students in the TTES condition scored twice as well as students in the standard instruction condition on these items.

Overall, these results suggest that the revised TTES strategies helped integrate the model with existing practice, facilitated greater cognitive depth, and were effective at supporting learning and transformative experience. Hayden’s opinion coincided with these results. In a concluding interview, he commented:

> I’ve seen more growth in these students this year and more depth of understanding in these students this year than in my 10 years of teaching. And my evidence would be from their case studies and their tests and how they could so deeply and so thoroughly explain their understandings of weather this year. I think that there’s definite value in a lot of what we’ve done.

Claims of effectiveness should be made with caution. The standard instruction condition was taught by a teacher with less experience and it is possible teacher effects played a role in the results. However, the pattern of year one and year two results suggests that there is more going on than teacher effects. First, Hayden’s classes representing the year two TTES condition showed a different pattern of change between the pre- and post-measure of transformative experience than his year one classes (see Figure 3). Second, even in year one, the intervention was effective for students with sufficient prior knowledge and an inclination toward transformative experience. Plus, it was effective at fostering greater multiple choice scores regardless of prior knowledge and engagement. Third, levels of transformative experience were heightened in the intervention condition compared not only to the standard instruction condition but also to those found in non-intervention classrooms in other studies of transformative experience in secondary science classrooms (Pugh, 2002; Pugh et al., 2010a). Nevertheless, we cannot fully discount teacher effects in the year two data.

Although connecting outcomes to specific strategies comprising the TTES model is difficult and was not a focus of the current study, interview participants were asked to provide feedback on the instruction. Most of the comments related to the case studies used as part of the experientially anchored instruction. When asked about the instructional methods used during the weather unit, many students stated that they found the case studies to be meaningful or valuable. One student commented, “It did matter, ‘cause you could make connections, and you could go back, and yeah, it was cool. Like the blizzard one, I could make connections to my life, ‘cause in the winter we get snow, yeah.”

A majority of students also commented on the difficulty of the case studies. As an example of mixed feelings about the case studies, one student responded, “I kinda liked the case studies, but they were kinda hard.” For some students, the difficulty combined with concerns about getting the right answer led them to dislike the project, “Even though I did good on it, I didn’t like it ‘cause it was research and stuff, it was hard. You didn’t know if you got the right answer on it.” However, it is also worth noting that some students expressed a great sense of pride in accomplishing a difficult project. One stated, “It’s hard work! While you’re doing it it’s like, oh man, I don’t get it! But then at the end, you’re like, wow, I kind of learned some more stuff there, I grew my understanding!” Another commented, “I found myself feeling more happy, ‘cause hey, I did that, I didn’t just read that out of a book and copy it down, I actually thought about it and researched it, I did that!”

Thus, from the students’ perspective, experientially anchored instruction was especially salient. Whether it is particularly important to the effectiveness of the TTES model needs to be explored in future research. However, it is worth noting that experientially anchored instruction was not used in teaching heat transfer and students interviewed in the TTES condition expressed lower levels of transformative experience for this topic compared to the other two. In addition, we did not find a statistically significant difference between conditions for this topic.

General discussion

The purpose of the current study was to evaluate the implementation of the TTES model and further develop this model in response to implementation challenges (Pugh & Girod, 2007; Pugh et al., 2010b). Strategies associated with the TTES model have been found effective in prior research, although such studies had limited generalizability. Heddy and Sinatra (2013) reported that the TTES model effectively facilitated transformative experiences and conceptual change more effectively than a comparison condition, but the study was conducted with college undergraduates, and the first author served as the instructor in both conditions, limiting external validity and generalizability to a K–12 environment. In studies conducted in K–12 contexts, researchers found TTES strategies to be more effective than alternative instruction at fostering transformative experiences (Girod et al., 2003, 2010; Pugh, 2002). Again, however, the TTES strategies were implemented by researchers, limiting external validity. In addition, prior intervention studies have been comparatively short in duration; thus, results may not be generalizable to a more realistic classroom setting where the duration is an entire unit or semester.

Pugh et al. (2010b) conducted an initial study of implementation of the TTES model by a practicing teacher and observed implementation challenges as well as mixed results in terms of effectiveness. We followed up on this study by using design-based methods to study implementation over a longer period of time and develop revisions to support implementation. In year one, we observed similar implementation challenges, thus confirming that the model may be difficult for teachers to apply in a deep and integrated manner. This finding is in line with research indicating the difficulty of changing practice (Tyack & Cuban, 1995; Marzano et al., 2005). We also observed mixed results in that the effects were mostly limited to students with an inclination toward transformative experiences and higher prior knowledge of the content.

In year two we worked with Hayden to develop revisions to the TTES model that would support more integrated and deeper implementation (see Table 1). The revised TTES model resulted in more integrated and deeper application of strategies reflective of second-order pedagogical change (Marzano et al., 2005). Moreover, this revised implementation yielded results in line with our predictions.

Thus, the current research confirms and builds on prior research on fostering transformative experience. The small scale and design nature of the study limits the rigor of the research. Nevertheless, as Berliner (2006) and others have argued, such research is important and relevant to practitioners. In particular, we hope the thick description of the implementation of the TTES model in the current study is useful for other researchers who want to explore the impact of the model and for teachers who are interested in implementing it in their classrooms, particularly in light of the call for guidance for teachers in developing an environment supportive of students' scientific inquiry (McNeill & Krajcik, 2008).

Contributions to research on pedagogy

The TTES model relates to a number of pedagogical models within and outside science education. A full review of connections is beyond the scope of this paper. However, we feel it is valuable to discuss a few of the most salient connections so researchers can synthesize ideas across pedagogical frameworks.

Within the broader engagement literature, the construct of transformative experience bears a particular association to the construct of interest (see Renninger & Su, 2012). Indeed, Pugh, Linnenbrink-Garcia, Phillips, and Perez (2015) argue that transformative experience can be considered both a trigger for the development of interest and a manifestation of a particular type of interest experience. In a review of research on strategies for fostering interest, Linnenbrink-Garcia, Patall, and Messersmith (2013) identified four common elements of situational supports: autonomy support, opportunities for active involvement, connections to real life, and instructor enthusiasm/approachability. The TTES model contributes uniquely to an understanding of how to capitalize on the last two elements. The design principles of framing content as ideas and scaffolding re-seeing are particularly focused on establishing connections to real life. Framing content as ideas helps students to appreciate and anticipate the potential of the content to enrich everyday experience. Scaffolding re-seeing supports students in their efforts to use content as lens for perceiving aspects of their everyday lives in meaningful new ways. By supporting transformative experience, these principles facilitate what might be termed "actualized" relevance; that is, an actual experience of content relevance in everyday experience outside the classroom. The design principle of modeling transformative experience connects with the instructor enthusiasm/approachability factor. Modeling one's experience with and value for the content in everyday experience is one way of conveying enthusiasm.

Related more specifically to science education and curriculum reform, the TTES model compliments research concerned with developing scientific inquiry, engaging students in thoughtful investigations of "authentic questions" (Krajcik et al., 1998). With this, the principles of the TTES model and specific activities such as the case studies align with inquiry-based curriculum projects, which have been identified as promoting student performance through understanding of scientific concepts and inquiry (e.g., Singer, Marx, Krajcik, & Chambers, 2000). For example, the use of case studies offered contextualizing driving questions to guide student engagement in authentic scientific inquiry in collaborative environments supported through teacher-provided scaffolding. The results of the current study suggest that case studies built from students' own experience and contextualized in the other TTES strategies support not only learning but engagement with content extending into everyday experience outside of school.

The TTES model further aligns with and contributes to research concerned with fostering aesthetic aspects of science learning. Hadzigeorgiou (2012) associates aesthetic learning with a sense of wonder and found that students developed more of a sense of wonder when teachers made deliberate attempts to evoke wonder in topic introductions (Hadzigeorgiou, 2012) or presented content in the context of a compelling story (Hadzigeorgiou, Klassen, & Klassen, 2012). Cavanaugh (2014) found that a sense of wonder could be evoked by teaching for the sublime in the context of science. She defined the science sublime as "feelings of awe and wonder that come only from a deep understanding" (p. 62). Her pedagogical model, which draws on Dewey's aesthetics, includes an emphasis on "calling attention to what is astonishing, terrifying, or unifying about the content" (p. 66). These strategies for evoking wonder are quite similar in method and intent to the TTES strategy of artistically crafting topic introductions. In a sense, both focus on identifying what is moving, powerful, or dramatic about the content and bringing this to the awareness of the students. However, the language and meaning are slightly different in that the above research focuses on evoking an emotional response of wonder and awe while the TTES framework focuses on evoking anticipation leading to action. We suspect that wonder and anticipation are closely linked constructs, and strategies for fostering one will support the other.

Limitations

The study was quasi-experimental and limited in scale in that it involved just two teachers. Teacher effects may have contributed to the results, although it is unlikely that they account for the larger pattern of results across years and outcomes. In addition, the participating teacher was experienced and possessed goals in line with the TTES model. Consequently, this teacher may have been more prepared to modify his practice in ways compatible with the model as teachers make sense of new models and frameworks in terms of existing practices and beliefs (Appleton & Asoko, 1996; Briscoe, 1996; Dwyer et al., 1991; Hashweh, 2003; Winitzky & Kauchak, 1997). The teacher also had time to learn to implement the TTES model. Even with a revised TTES model facilitating more integrated and deeper implementation, it is likely unrealistic to expect a teacher to immediately implement the model fully as this conflicts with teacher change as a gradual and developmental process (Tyack & Cuban, 1995; Marzano et al., 2005). Related to teacher implementation of the TTES, the present study is also limited by the presence of a single researcher observer in both year one and year two. While the lead researcher's observations provide valuable insights into the challenges and successes of implementing the TTES model, classroom activities, and classroom dynamics, lack of additional observers limits the ability to verify these observations, thereby limiting interpretations and conclusions that may be drawn based on observations.

Another limitation relates to the difficulties of assessing transformative experience. Because the construct of transformative experience focuses on events occurring at unpredictable times and places in students' everyday experience, there is a necessary reliance on self-report. Unfortunately, the validity of self-reports has been called into question (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003), and transformative experiences may present unique challenges in that students may not be able to accurately recall instances in which they applied content in everyday experience. That is, students' self-reported transformative experience likely does not align fully with their actual everyday experiences with the classroom content. In an attempt to counteract this limitation, the current study used both survey and interview methods and found consistent results across both. However, both methods rely on self-report and are subject to self-report concerns. Further, member checking was not employed to verify participating teacher and student interview responses and accuracy of interpretations (Merriam & Tisdell, 2016). However, Morse, Barrett, Mayan, Olson, and Spiers (2002) also argue that, with the exception of case study and narrative inquiry, member checking serves limited purpose because responses have been abstracted and decontextualized for the purposes of analysis.

The difference between pre- and post-measure scores on the transformative experience survey may also reflect a measurement issue. With the exception of the year two TTES condition, students, on average, reported lower levels of engagement on the post-measure. This pattern may reflect findings that motivation variables such as interest and task value decline over time in a course (e.g., Zusho, Pintrich, & Coppola, 2003; Frenzel, Goetz, Pekrun, & Watt, 2010). However, due to its more general nature (i.e., items targeting science instead of specific content), the pre-test may be more subject to positive response bias.

Future directions

Future research on the TTES model is needed along two lines. First, scale-up designs are needed to evaluate the effectiveness of the revised model when implemented at the department, school, or district level. In addition, scale-up designs would allow researchers to evaluate implementation in relation to teachers' backgrounds, attitudes, and experience. Second, microgenetic studies are needed to explore the connection between specific strategies and transformative experience. Such studies would help build the base of knowledge regarding supports for transformative engagement and the mechanisms by which they function.

Conclusion

Fostering transformative learning has long been a goal of educators and educational philosophers such as Dewey. Movies such as *Dead Poets Society* extol the virtues of teachers who transform the way students experience the world, and many individuals can recall with fondness a teacher who transformed their own perceptions of the world. However, research-based instructional models for fostering transformative experiences have been lacking. The current study built on past efforts to develop the TTES model. Results showed that a revised form of the model developed in the context of the study was effective at fostering higher levels of transformative experience and learning. We hope this revised model can now be used to support science teachers in their efforts to improve learning and make science education transformative.

Notes

1. Transformative experience is not the same as transfer. Instead it is a more holistic construct focusing on the choice, as opposed to ability, to apply learning and the meaning such action has in everyday experience.
2. There were no differences in item functioning or intervention results using the pooled data to generate Rasch scores instead of just the year one data.
3. Three multiple-choice items worth 2 points; three worth 1 point (9 total possible). Open-response items scored on a 0-to-2 scale (12 total possible).
4. Ten multiple-choice items worth 2 points; three worth 1 point (23 total possible). Open-response items scored on a 0-to-2 scale (14 total possible).
5. The homoscedasticity and homogeneity of variance assumptions were met. However, the homogeneity of regression assumption was not met as discussed in the text.
6. Partial eta squared (η_p^2) is the proportion of variance explained by an effect and that effect plus its associated error variance. Cohen (1988) suggests .01 = small, .06 = medium, and .14 = large.
7. Gelman and Park (2008) recommend splitting the data into thirds or quarters over doing a median split.

8. The homogeneity of regression, homoscedasticity, and homogeneity of variance assumptions were met.
9. The homoscedasticity and homogeneity of variance assumptions were met. However, the homogeneity of regression assumption was not met, as discussed in the text.
10. The lower consent rate in the standard instruction condition was a consequence of the standard instruction teacher not clarifying for parents that they had to sign a separate line to consent to interview participation.
11. Multiple-choice items worth 2 points each (32 total). Open-response items scored on a 0-to-2 scale (6 total possible).
12. Multiple-choice items worth 2 points each (40 total). Two open-response items scored on a 0-to-2 scale and five scored on a 0-to-3 scale (19 total possible).
13. Homogeneity of regression and homogeneity of variance assumptions were met. However, the homoscedasticity assumption was violated due to an extreme outlier (very high level of transformative experience compared to others). We conducted the same analysis with this outlier dropped and found the same results ($p = .004$), with the exception that the effect size was slightly lower ($\eta_p^2 = .05$). We report the results including the outlier, as the interview results for this individual were also quite high, suggesting that the outlier represents valid data.
14. The homogeneity of regression, homoscedasticity, and homogeneity of variance assumptions were met.
15. The homogeneity of regression and homoscedasticity assumptions were met, but the homogeneity of variance assumption was not met for the air pressure and weather ANCOVAs. In both cases, the TTES condition displayed greater variation. However, the *F* test is robust to this violation when sample sizes are relatively equal as is the case with these data (Tabachnick & Fidell, 2007).
16. The homogeneity of regression, homoscedasticity, and homogeneity of variance assumptions were met.
17. The homogeneity of regression assumption was met and, after a square root transformation on the outcome variable, the homoscedasticity and homogeneity of variance assumptions were met.

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Appendix A: Interview Guide

Construct	Primary interview questions and sample follow-up prompts
Motivated use	
Application in everyday life	Did you ever think about or apply the things you learned about [air pressure/heat transfer/ weather] in your everyday life? By everyday life, I mean your life outside of school. Did you ever think about what was causing [the weather]? Did you notice any examples?/Can you give me an example of [air pressure/heat transfer/ weather] in your everyday life? Did you notice any other examples? Is that something you thought about in the moment or something you thought about just now [i.e., prompted by the interview]? Did you talk to anyone else about [air pressure/heat transfer/weather] outside of school? When you were talking to [someone], were you just answering a question [they] had, or were you talking about [topic] because you found it interesting? Did you watch any shows on TV about [air pressure/heat transfer/weather]? Would you say you paid more attention to [the weather reports] than you did before the unit? Did you watch that show because science class got you interested in it, or would you have watched it anyway?
School-prompted interest	Did you read anything on your own about [air pressure/heat transfer/weather], and by on your own I mean did you choose to read something even though it wasn't required for school?
Expansion of perception	Do you think about [air pressure/heat transfer/weather] differently than you did before? Now that you learned about [air pressure/heat transfer/weather], would you say that you think differently about how some things work or why some things happen? How do you think about [it] differently? Can you give me an example/think of a specific example of how you think about it differently?
Experiential value	Are the ideas you learned about [air pressure/heat transfer/weather] interesting? Did learning about [air pressure/heat transfer/weather] make the world or your life more interesting or exciting? Could you give me an example? Did it make you interested in how things work or any particular events? Are the ideas you learned about [air pressure/heat transfer/weather] useful? Do you think it's useful for your current everyday experience or useful for the future?

Appendix B: Interview Coding Scheme and Representative Responses

Code	Motivated use	Expansion of perception	Experiential value
0: Student does not endorse the characteristic.	**Did you ever think about or apply the things you learned about air pressure in your everyday life, and by everyday life I mean your normal life outside of school?** Um, no.	**Do you think about heat transfer differently than you did before?** I don't even really know what heat transfer is.	**Did learning about weather make the world or your life more interesting or exciting?** No.
1: Student endorses the characteristic but is unable to provide a valid example or explanation.	**[Did you] watch any or read any weather reports?** I pretty much watch weather every morning because my parents turn it on. But yeah, I understand it more now. About air pressure and stuff. **Did you start paying more attention to it when you started learning about weather in science class?** A little bit, yeah. [No further explanation or example.]	**Do you think differently about heat and heat transfer than you did before?** Yeah. **OK, can you give me any examples?** Not really, I just think about it differently. **OK, does it make you think differently about how some things work or how some things happen?** Yeah. **OK, could you give me any examples?** No.	**Do you think these ideas are useful for your current everyday experience?** Um, yeah, I think so. **OK, do you have any ideas why you think they're useful?** No, not really.

(*Continued on next page*)

Appendix B: (Continued)

Code	Motivated use	Expansion of perception	Experiential value
2: Student endorses the characteristic and is able to provide a valid example or explanation.*	**Did you notice any examples of heat transfer in your everyday life?** Yes, because I cook sometimes, and I have problems with touching the pans. I mostly get the mitts, but sometimes when I'm stirring, my hand touches it, and I get a burn, and that's conve—conduction.	**Any other things you think about differently than you did before?** Water vapor … I learned how the mist is actually water vapor in the air and then water vapor is like all around us and you have to find how much water vapor is in the air so I thought that was pretty cool.	**Are the ideas you learned about air pressure, heat transfer, and weather interesting?** I think that weather is a little bit more interesting because now I kind of know how to determine the weather without having to look at all the complicated meteorologist stuff.
3: Student endorses the characteristic and is able to provide multiple valid examples and explanations or a particularly detailed and enthusiastic example and explanation.	**Did you ever think about or apply the things you learned about air pressure in your everyday life? By everyday life I mean your life outside of school.** Yes, 'cause when I was driving in the car after the concert, I saw a bunch of clouds, and I was telling my parents, "oh that's a cumulonimbus cloud," and like they were like, "what?" And I was like, "it's gonna rain!" And they were like, "ohhh." And then a few weeks after we did the weather charts and the cold fronts. I was watching the weather with my parents and stuff, and I saw the blue line with the squares on it, and I'm like, "oh, there's gonna be a cold front soon," and then I saw high and low pressure between Colorado, and I said, "it's gonna be windy so, um, prepare yourself."	**Do you think about heat transfer differently than you think before?** Yeah, I really didn't know that. I knew that radiation came from the sun. Convection reminded me when we did the rocks unit where we look at the earth they show the convection currents; it was like spinning. **So you think about that differently than you did before?** Like with the convection currents. After we learned about that, my mom was like boiling some water. I kind of like sat there for a little bit. I think she was boiling noodles and I watched the noodles spin in certain ways so you can see the boiling water go up and come back down and stuff. **You mentioned another example [previously in the interview], like the windows?** Yeah, like they have the double pane windows. My dad had bought some double pane windows to replace the skylights and I really wondered what's the differen[ce] between the double pane and normal and now I understand why they have the double pane.	**Are the ideas you learned about air pressure, heat transfer, and weather interesting**? Um, yeah, I think they're pretty interesting 'cause when I see a bunch of rain, I think um, it's gonna evaporate … I know it's gonna evaporate because of some type of heat transfer, and then it's gonna rain again, 'cause it evaporates and it's just the cycle of rain and stuff. And so when I see that, it's pretty interesting to me, 'cause I learned about the water cycle when I was in first grade, but then now, since I've learned more about it, I can put it together and know why it rains, definitely … I thought it was most interesting that I could learn about weather and I can see how it's made. I, like [another student], I don't have a future in weather, I don't want a future in weather, but, um, it's really cool just to know it and feel smart about it, and so that's what I like.

Note. *For motivated use, a score of 2 was also assigned if students reported both applying the content in everyday experience and engaging in school-prompted interest even if they were not able to provide valid examples/explanations.