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Exploring the influence of using the Teaching for Transformative Experiences in Science (TTES) model in an online teaching unit on high school biology majors' conceptions of biological evolution

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List of Abbreviations

Abbreviation	***Meaning***
TTES	Teaching for Transformative Experiences in Science
AU	Active use
EP	Expansion of Perception
EV	Experiential Value
PB	Perception Board
ERS	Evolutionary Reasoning Scale
TES	Transformative Experience Survey
CCM	Conceptual Change Model
Unit	Online evolution teaching unit that is based on the TTES model qualities

ABSTRACT

A person's worldview has a profound influence on her/his decision-making. The value a person attributes to a particular subject might determine the extent of its allowed influence, and the person's tendency to engage with the subject independently. For example having a scientific worldview is an important part of science literacy, that is known to effect a person's decision-making. It appears that deeply influencing students' scientific worldview, the value they assign to it, and their tendency to independently cognitively engage with the subject is possible when teaching is designed according to the *Teaching for Transformative Experiences in Science* (TTES) *model*. The profound effect the TTES model has, makes it important to use for essential subjects, like evolution, that might profoundly contribute to the student's scientific literacy. Evolution is extremely important both as a core concept in biology, and as a key to its understanding. Yet, evolution is a difficult subject to comprehend, as testified by the variety of alternative conceptions that are highly prevalent among the general public and among students from all levels of education. Here I asked whether it is possible to influence students' scientific worldview of evolution and its comprehension using an online evolution teaching unit that is designed according to the TTES model. To answer this question I have designed an online evolution teaching unit according to the TTES model. The TTES model was previously used only solely as a classroom teaching model. The unit is aimed to encourage the use of evolution concepts beyond the classroom experiences, inspire recognition of evolution's value for the student, and motivate the expansion of perception regarding evolution. Students from different classrooms in different schools learned evolution through the unit. Evidence of a transformative process, and of conceptual change toward the scientific view of evolution appeared, along with intriguing characteristics of the evolution learning process. These evidence constitute proof of concept for the feasibility of a transformation in the students' worldview regarding evolution through the online evolution teaching unit, which render a continued design research worthy.

Prologue

My journey started five years ago. As part of my final project for the non-thesis M.Sc. Rothschild-Weizmann Program, I carried out an action research to explore the influence of the Pugh and Girod’s (2007) TTES model on the alternative conceptions of ten eleventh grade biology majors regarding biological evolution. This study, which was conducted in 2017-2018, presented evidence of a transformative learning process leading to a conceptual change among my students. In that study I have noticed that the conceptual change seem to last for a month after intervention, suggesting knowledge retention. A similar result was also mentioned in a research examining the influences of implementation of the TTES model on fifth grade science students (Girod, Twyman, & Wojcikiewicz, 2010). Upon my return to the Feinberg graduate school, as an M.Sc. student of the science teaching department, I resumed the research, statistically analyzed the previous results, and turned to look further into the subject of knowledge retention. The participants of my previous study acceded taking part in the study and completed online questionnaires during the year 2020. Some of the participants also took part in interviews. A thorough analysis revealed a significant conceptual change accompanied by short and long-term knowledge retention following learning evolution through the TTES Model. The article presenting these findings is currently in writing (See Appendix E). At this point I was looking to expand the examination of the TTES model influence on high school biology majors’ worldview regarding evolution: to reach a larger sample, to neutralize my own possible effect as the teacher, and to examine whether it is possible to motivate a transformative process and/or a conceptual change via teaching using an online evolution teaching unit. The online unit which I developed is based on the TTES model, on the previous TTES based unit I developed for teaching in my own class and on my experience of teaching evolution through the unit. This thesis portrays the results of this endeavor.

INTRODUCTION

A scientific worldview

A worldview (or “world view”) is the complete outlook one have on life, nature and the universe. It is a system of assumptions and believes that influence thinking (Cobern, 2000), and create a perspective, from which values and attitudes derive. This perspective is used to describe the physical and social reality, and may have powerful effects on cognition, affect and behavior (Koltko-Rivera, 2004). A person’s worldview provides a nonrational foundation for thought, emotion and behavior, as well as presuppositions about what constitutes valid and important knowledge about the world (Cobern, 1996, p. 584). In this sense, a person that describes herself as having a scientific worldview, is a person who would hold the presupposition, that scientific knowledge constitutes valid and important knowledge about the world. Following this example, it is no wonder that having a scientific worldview is recognized as an important part of science literacy, that in turn constitute a main goal for science education (Cobern, 1996; Israeli Ministry of Education, 2016).

Learning is a vastly researched subject. It is a human characteristic, that is built into the core of our central nervous system’s activity (Dudai, 2004; Frankland, Josselyn, & Köhler, 2019; Weiller & Rijntjes, 1999), and encapsulate all the activities responsible for the way our perspectives and knowledge form, transform and change (Vaughn, Brown, & Johnson, 2020). We all learn through our lives, and the knowledge we consequently hold on to, is known to influence our continued learning (Ausubel, Novak, & Hanesian, 1968). Since every learning experience a person’s have is a part of what J. Dewey (1986) referred to as the experiential continuum, it comes as no surprise that through the last forty years learning developed to be performed in mediums as computers and online environments. This situation created the need for relevant terms and research as to the connection and influence of the learning medium on learning. Online learning, which is a digitally delivered instruction that supports learning (Mayer, 2019), for example, has continuously been a focus of education research and has been awarded many names according various criteria such as the centrality it takes as part of learning, the focus on teaching or the learners, and the learning environment involved (Singh & Thurman, 2019). The term hybrid learning represent learning that occurs through a virtual space as well as a physical space (Skill & Young, 2002). It may be represented in many possible models such as e-learning at a distance and learning non virtually at school, using a blended learning in which online learning is done both, in campuses or schools and at home, and varied degrees among them. There was also an attempt to create a unified taxonomy that would categorize blended learning (Staker & Horn, 2012). Yet, online learning, is still learning, and being such, its relevant research greatly contributed to the science of learning (i.e., how people learn), the science of instruction (i.e., how to help people learn), and the science of assessment (i.e., how to determine what people have learned) (Mayer, 2019, p. 4).

The connection between worldview and learning is reciprocal; A person's worldview is perceived as the "backbone" on which cognitive and perceptual frameworks are built throughout learning, and formal education (as other forms of learning) is thought to contribute to worldview evolvement (Cobern, 2000). That means a student's worldview serve as an interpretive framework for encountered phenomena, while learning experiences interact with the student's worldview, and might influence it, and the cognitive and perceptual frameworks it supports. By this regard, learning about students' worldview may offer a better understanding of their conceptual structure (Koltko-Rivera, 2004), and consequently provide a greater understanding of their conceptual change (Cobern, 2000). Conceptual change refer to changes that occur in students' perception of a concept. The change is characterized as prime, at the level of the individual core concepts (Disessa & Sherin, 1998). In the context of developing a scientific worldview, a conceptual change would be a change in the perception of an elemental concept, from an alternative conception to a scientific one. An alternative conception is defined as the understanding of a real-world phenomenon in a way that is not consistent with the scientific explanation or model of that phenomenon (Modell, Michael, & Wenderoth, 2005). Holding to an alternative conceptions in known to raise difficulty in understanding scientific concepts, and building correct scientific models (Coley & Tanner, 2015; Gilbert & Watts, 1983; Kowalski & Taylor, 2017; Leonard, Kalinowski, & Andrews, 2014; Modell et al., 2005; Taber, 2017). It is suggested, that just as properly learning a meaningful word in a new language means learning the deep cultural meanings the word is rooted in, becoming scientifically literate means coming to know and understand (though not necessarily embrace) a new view of the world (Cobern, 1996). This idea sets conceptual change in its widest meaning as an integrated process in the development of scientific worldview, and scientific literacy, and marks conceptual change as an accompanying goal of science literacy for science education. Achieving this goal is not trivial, and practically goes through the use of a conceptual change model.

Conceptual change models

For many years, the dominant working model for dealing with alternative conceptions, while providing the theoretical foundation required to explain instances of conceptual change (Demastes, Good, & Peebles, 1996), was the *conceptual change model* (CCM) (Posner, Strike, Hewson, & Gertzog, 1982). This model was based on Piaget's process of accommodation (Huitt & Hummel, 2003) and regarded conceptual change as a process of concept substitution. The main strategy of the CCM involved characterizing a concept's stature (it's intelligibility, plausibility, and it's fruitfulness), undermining that concept's position, and offering the students a scientifically accepted rival concept, with a higher status, to invoke substitution (Posner et al., 1982). The CCM was extensively researched and proven effective in promoting conceptual change (Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010). However, advances in the perception of cognitive structure, characterized concepts as complex clusters of ideas that are bound together, rather than independent separate units. This constructivist theory of *knowledge in pieces*, offered a theoretical perspective that viewed conceptual change as a process of knowledge refinement and reorganization. The authors perceived students' conceptions as material for the conceptual change process, and the process of conceptual change itself as a development within a complex system (Smith III, Disessa, & Roschelle, 1994). The theory challenged the mechanism suggested by the CCM. From its perspective, a learning process that consists of replacing perceptions was deemed less valid, and conflicted with the constructivist idea of learning as an adaptation of prior knowledge. Pieces of knowledge that are abandoned with the substitution could not have been used as a learning resource. (Smith III et al., 1994). The CCM theory focused on the cognitive aspect of reality perception, and did not regard affective, behavioral or sociocultural aspects. In later years, two of the theory authors offered an expansion to the theory, that acknowledged the influence of other aspects such as emotion, values and aesthetics on the construction of meaning (Strike & Posner, 1992).

Other theories added motivational and affective dimensions to the conceptual change model's process. Dole and Sinatra's (1998) *cognitive reconstruction of knowledge model* combined critical elements from cognitive psychology, science education, and social psychology. The model characterized the interaction between an input message and the learners, while considering the learners' existing conceptions and their motivation to process the information in the received message. They pointed out that strong metacognitive engagement is a key component in enabling long-lasting conceptual change (Dole & Sinatra, 1998). Similar to the cognitive reconstruction of knowledge model, Gregoire (2003) *cognitive–affective model of conceptual change* considered the message, but it emphasized the psychological viewpoint of the message receiver and the affective appraisal of the message as a step leading to cognitive processing.

An approach that considers both sociocultural and cognitive influences as critical catalysts of conceptual change, and offers a framework that integrates these components, is the *belief and knowledge acquisition and change framework* (Murphy, 2007). This framework places the learner at the center and explores the relationship between knowledge and belief from an epistemic point of view. According to this framework, the distinction between knowledge and belief is important, because the process of knowledge acquisition and change proceeds from belief and knowledge as separate constructs to an overlapping construct. Optimal learning is achieved when students' beliefs, which are generally socially enculturated, are integrated with their cognitively reasoned understanding (Murphy, 2007, p. 44).

The presented conceptual change models left room for a model that offers a holistic approach that binds the behavioral, cognitive, and affective dimensions together, in a contemporary sociocultural context. Such an experience based model that integrates these dimensions is the *Teaching for Transformative Experiences in Science* (TTES) *model* (Pugh, 2020; Pugh, Bergstrom, Heddy, & Krob, 2017; Pugh & Girod, 2007).

The Teaching for transformative experiences in science (TTES) model

The TTES model was constructed based on J. Dewey's (1938) theory, which claimed that education should expand the individual perspective beyond classroom experiences to the outside world. This theory delved into the transformative nature of human experiences as a path toward meaningful learning, while emphasizing an aesthetic view of the world as beneficial for the development of a broader view of it (R. E. Dewey, 2012). The TTES model basically defines three qualities, that when experienced in an integrated manner, testify to the transformative nature of the experience in regard to the student's worldview. The TTES model three qualities are: experiential value (EV), expansion of perception (EP), and active or motivated use of concepts (AU) (Pugh & Girod, 2007), these qualities roughly correspond to the behavioral, cognitive, and affective dimensions, respectively (Pugh, Bergstrom, & Spencer, 2017). EV describes the degree to which the student identifies and appreciates the meaningful contribution of the learned perception/new worldview to his/her personal life experiences. EP describes the degree to which changes in the student's perception broaden and deepen his or her worldview, so that the world is perceived through a content lens and is layered with meaning. AU, also referred to as motivated use (Pugh, Bergstrom, Heddy, et al., 2017), describes the degree to which the student, of his/her own accord and without directive or solicitation, uses learned terms, concepts, and ideas, especially in real-life contexts, i.e., outside the classroom. Since aesthetic understanding enhances the transformative quality of the learning experience by both strengthening the EV and merging the in-school and out-of-school experiences (Girod, Rau, & Schepige, 2003), it is related to implementation of the model qualities.

Studies implementing the TTES model were conducted with biology undergraduates, high-school students and elementary-school students, and presented significant conceptual change (Girod et al., 2010; Heddy & Sinatra, 2013; Pugh et al., 2010), conceptual understanding (Girod et al., 2010; Pugh, Bergstrom, Heddy, et al., 2017), increased interest and efficacy (Girod et al., 2003; Girod et al., 2010), high levels of engagement (Heddy & Sinatra, 2013; Pugh, Bergstrom, Heddy, et al., 2017), and increased levels of enjoyment (Heddy & Sinatra, 2013).

The TTES model was processed into an instructional strategy for formal education setting, that facilitates transformation and conceptual change, while considering the student's prior perception, and aspires to broaden the student's perspective while stimulating awareness of the experiential value of the subject at hand (Heddy & Sinatra, 2013; Pugh & Girod, 2007; Pugh et al., 2010). The main three principles of instruction were: (a) *framing the content as ideas*, (b) *scaffolding re-seeing*, and (c) *modeling transformative experiences*. Pugh and Girod (2007) contention was that ideas have the potential to transform one's relationship with the world by opening up new experiences and allowing us to see and act on the world in new ways. They depicted re-seeing as inviting students to attach new perspectives to ordinary objects, and modeling transformative experiences as modeling passion for the content (Pugh & Girod, 2007).

The TTES implementation design model and classroom strategies

The TTES model includes a design model based on three main principles, that are meant to inspire, support and establish the TTES model three qualities: EV, EP and AU. The first principle is ***framing content as ideas*** (Pugh, 2011; Pugh, Bergstrom, Heddy, et al., 2017; Pugh et al., 2010), which means presenting the content as ideas, possibilities that one might choose to explore in everyday life context. This principle should inspire AU and support the development of EV (Pugh, Bergstrom, Heddy, et al., 2017). The second principle is ***scaffolding re-seeing*** (Heddy & Sinatra, 2013; Pugh, 2011, 2020; Pugh, Bergstrom, Heddy, et al., 2017; Pugh & Girod, 2007; Pugh et al., 2010), which means guiding and assisting the students to reach the goal of re-seeing the world through the content lens. This principle should support the EP (Pugh, Bergstrom, Heddy, et al., 2017). The third principle is ***modeling transformative experience*** (Girod et al., 2003; Heddy & Sinatra, 2013; Pugh, 2011, 2020; Pugh, Bergstrom, Heddy, et al., 2017; Pugh & Girod, 2007; Pugh et al., 2010), which means sharing personal transformative experiences while expressing enthusiasm for the content. This principle should inspire AU, establish EV, and much like the principle of scaffolding re-seeing, support re-seeing (Pugh, Bergstrom, Heddy, et al., 2017), and thus should support EP.

Interestingly, these same principles are expressed by different strategies and very different teaching methods in different research articles implementing the TTES model. At the elementary school level, the teacher-researcher was dominant in teaching and led learning and discourse. The teaching activities took place in the classroom and outside the classroom (Girod et al., 2003). At the middle and high school level, the closely guided teacher or the teacher-researcher led the class through an array of diverse methods: discussions, hands-on activities (as group lab work), demonstrations, media inspection (commercial videos, newspaper), and individual work with worksheets (Pugh, Bergstrom, Heddy, et al., 2017; Pugh et al., 2010). At collage level teaching was performed in front of a learning hall in a manner of PowerPoint lectures, accompanied by discussions, that were led in small groups (Heddy & Sinatra, 2013; Heddy, Sinatra, Seli, Taasoobshirazi, & Mukhopadhyay, 2017). These different teaching methods used as an implementation platform for the design model principles (framing content as ideas, scaffolding re-seeing and modeling transformative experience) and might have influenced the amplitude and scatter of the different strategies chosen to express the design model principles.

Framing content as ideas (as appose to a set of facts) has to do with both the uncertain nature of an idea that compels the learner to contemplate the idea as a possibility, and the appealing notion of being involved with something that might influence the learner and be influenced by the learner. The anticipation for using and testing the ideas in everyday life, drives the student toward AU, while thinking of the ideas potential in everyday life context may prompt the student toward recognizing it's EV. The strategies used to express this principle at the elementary school level were presenting content as artful and compelling ideas and asking students to be more imaginative and creative as they wonder about the ideas potential (to ask the question "what if?") (Girod et al., 2003). At the middle and high school level this principle was expressed by the use of metaphors to generate anticipation and present the content as compelling possibilities (Pugh, Bergstrom, Heddy, et al., 2017), whereas at the college level the strategy was direct. The word "ideas" was used when speaking of knowledge, and the students were asked to think of the ideas out of school (Heddy & Sinatra, 2013).

Scaffolding re-seeing is a challenging principle, yet it's implementation makes the transformation surmountable. Since re-seeing is viewing an object, a phenomenon or a situation differently in light of learned ideas, the reseeing scaffold stretches between the students' current worldview and the students' unknown future worldview. Dealing with the cognitive aspect of the TTES model, the EP, the implementation strategies for this principle are allegorically the external construct that allows for the building of the growing infrastructure of the students' expanding worldview. The strategy used to scaffold re-seeing at the elementary school level was to provide abundant opportunities for the students to explore the world while wondering about the science ideas, and their influence on their worldview. (Girod et al., 2003). At the middle and high school level scaffolding re-seeing was expressed by structuring and escorting the perception evolvement process. Starting by locating suitable objects for re-seeing, through orchestrating re-seeing activities and practicing re-seeing with the students (and modeling it) (Pugh et al., 2010). The students experiences also used for scaffolding re-seeing by enabling students to share their independent re-seeing experiences related to the content (Pugh, Bergstrom, Heddy, et al., 2017; Pugh et al., 2010), delving into the students reported experiences by using them as case studies for advancement, and keep connecting the learned content to real-world phenomena (Pugh, Bergstrom, Heddy, et al., 2017). The college level implementation strategy to scaffold re-seeing is completely different, and offers the transformative experience qualities (Experiential Value, Expansion of Perception & Active Use) as organizing qualities for learning. The students are expected to analyzed class content examples according to this qualities: to estimate how it changes and widens their perspective (EP), what value it bears for them (EV), and where would they use it in everyday life (AU) (Heddy & Sinatra, 2013; Heddy et al., 2017). The students are encouraged to practice by sharing their everyday content relevant experiences with each other, and analyzing these experiences using that organizing principle (Heddy et al., 2017).

Modeling transformative experience is a design principle that strengthens the prior design principle of scaffolding re-seeing, and inspires transformation. In the TTES model Modeling transformative experience means sharing the teacher's own experiences, and worldview as they are seen through the lens of the ideas presented (content), and the worldview / those experiences / learning experiences assigned value. The modeling is meant to inspire and to provides sort of a map for the building of the students worldview by scaffolding student experience (Pugh, 2011). The implementation strategies for this design principle do not differ among different school level. The strategies for modeling AU include the teacher sharing personal experiences and examples as to how the teacher uses the ideas (Girod et al., 2003; Heddy & Sinatra, 2013; Heddy et al., 2017; Pugh, Bergstrom, Heddy, et al., 2017); exemplifying or referring to the way another person (e.g. a competitive athlete) uses the learned ideas (Heddy et al., 2017); and exhibiting authentic enthusiasm for the ideas/content (Pugh, Bergstrom, Heddy, et al., 2017). The strategies for modeling EP are remarkably similar: teaching ideas/concepts from the teacher's experience, and sharing the way these ideas expanded the teacher's and other peoples' worldview (Heddy & Sinatra, 2013; Heddy et al., 2017; Pugh, Bergstrom, Heddy, et al., 2017; Pugh et al., 2010). Two main strategies are reported for modeling EV: drawing attention for possible use and value the ideas/content have in the students' everyday experiences (Pugh et al., 2010), and exemplifying the teacher's own perceived value for the ideas and their transformative fortitude (Girod et al., 2003; Heddy & Sinatra, 2013; Heddy et al., 2017; Pugh, Bergstrom, Heddy, et al., 2017; Pugh et al., 2010).

There is another strategy that was mentioned in different phrasings in research, though it was not tethered to a specific design principle, and that is teaching in informal learning environments (Pugh et al., 2010). It is mentioned that students' engagement with transformative experiences, while in the zoo was considered to be a free-choice transfer. That is "the application of knowledge or skills to tasks that differ from the learning tasks or in contexts that differ from the learning context" (Pugh et al., 2010, p. 277), that is not required by task. It stands to reason that a change in situation allows for students who value the learned concept, understand it. and perceive it as a part of their worldview, to use the learned concept in a different situation. The strong engagement with a transformative experience expresses itself as transfer. The literature states that the pedagogical design principles (*framing content as ideas, scaffolding re-seeing and modeling transformative experience*) are effective at fostering motivation to transfer (Pugh, Bergstrom, Olson, & Kriescher, 2021). Since the TTES model quality of AU is considered to be an example for free-choice transfer (Pugh et al., 2010). A plausible explanation for the mention of integrating informal learning environments as a TTES model implementation strategy lay with its offered opportunities to detach ideas from the classroom, and thus support the TTES model implementation by supporting AU.

It seems there are many different routes leading to the goal of transformative experiences. This raises the challenge of choosing the correct paths for a specific set of presented circumstances. A quick assessment might lead to the students level (elementary, secondary or college) as a mean for choosing the right path. However, the cause of choosing different teaching methods and for adjusting the implementation strategies for different level of students might stem from wishing to cling to a representation of instruction that is typical of the classroom’s level (Heddy & Sinatra, 2013), rather than concrete evidence of compatibility.

It is important to notice that despite the difference in the teaching methods and in the implementation strategies, the mentioned research articles adhered to the spirit of the TTES model’s qualities (AU,EP & EV). This is important because of the role the philosophy takes in the model. According to Pugh (2011), one of the main TTES model’s thinkers and architects, the philosophy helps us keep sight of what matters most: “meaningful experience as a life goal” (Pugh, 2011, p. 108). Since Pugh’s work weaves experience and learning together in a reciprocal influence relationship (Pugh, 2011), it is prudent to assume that as long as the transformative experience philosophy is kept in sight and is aligned with intention while the implementation strategies are adjusted and crafted to the situation and the students, we will not distant ourselves from the TTES model’s known implementation outcomes.

Evolution as a subject for fostering transformation

A worldview is constructed from abstract concepts and hypothetical objects. It is the infrastructure of a person’s conceptual framework. Thus, constitutes a difficult built to disconfirm. The consequences of a worldview disconfirmation may either be catastrophic or transformative (Koltko-Rivera, 2004). The TTES model is a subtle approach. It does not aim to rattle or undermine the students’ existing worldview, rather than inspire the expansion of perception, driven by the students’ recognition of the perceptions value to their life, and from internal motivation to do so. Nonetheless, since a worldview has a major influence over a person's thoughts and experiences (Cobern, 2000), it is important to use the TTES model for essential subjects, that might profoundly contribute to the student's scientific literacy. This notion applies for choosing both, the teaching subject, and the teaching content. As stated: *"...selecting content worth teaching is a critical step toward fostering transformative experiences*" (Pugh, 2020, p. 31).

There is overwhelming acceptance among scientists and science education organizations of the veracity and centrality of evolution and its power as a unifying concept in biology (Pobiner, 2016, p. 232), where evolution is a core concept (Coley & Tanner, 2015). In fact, a complete understanding of modern biology cannot be achieved without understanding evolution (Bishop & Anderson, 1990, p. 415). The documentation of significant difficulties in understanding and accepting the theory of evolution is therefore quite worrisome. These difficulties are often expressed in a variety of alternative conceptions (Bishop & Anderson, 1990; Flanagan & Roseman, 2011; Gregory, 2009; Shtulman, 2006; Sinatra, Brem, & Evans, 2008; M. U. Smith, 2010), which are highly prevalent among the public and students from all levels of education (Pobiner, 2016). An example alternative conception is the claim that organisms have an essence (essentialism), and that changes in a population indicate organism transformation and a change in essence; this transformational point of view, as opposed to the scientifically accepted variational view of evolution, disregards major aspects of evolution and therefore hinders comprehension of evolution (Bishop & Anderson, 1990; Shtulman, 2006; Shtulman & Calabi, 2012). Indeed, students' alternative conceptions of evolution have been identified as a significant impediment to conceptualizing, understanding, and building a scientific grasp of the evolution model, as well as to accepting the theory of evolution (Pobiner, 2016; Sinatra et al., 2008; M. U. Smith, 2010). It seems clear that attending to students' particular alternative conceptions during instruction is imperative to the successful learning of evolution.

A correct perception of evolution elemental concepts, and of the evolution mechanism is undoubtedly imperative for fully understanding and accepting evolution. Combining that notion, with the essential role the understanding and accepting evolution takes in developing scientific literacy, inevitably leads to declaring evolution as a worthy and a perfectly suited subject for TTES.

RATIONAL & OBJECTIVE

Teaching evolution while implementing the TTES model to biology undergraduates and high-school students resulted in reported transformative experiences accompanied by a significant conceptual change (Heddy & Sinatra, 2013; Pugh et al., 2010), high levels of engagement (Heddy & Sinatra, 2013; Pugh, Bergstrom, Heddy, et al., 2017), and increased levels of enjoyment (Heddy & Sinatra, 2013), as described above in the Introduction. However, different studies, which complied with the TTES design model principles, applied different implementation strategies (Girod et al., 2003; Heddy & Sinatra, 2013; Heddy et al., 2017; Pugh, 2004; Pugh, Bergstrom, Heddy, et al., 2017; Pugh et al., 2010). It seems that they all require an expertise in implementation and adaptation of the model at the level of the teacher, the students, the subject, and the learning process, i.e. a deep understanding of the model and the philosophy it is based upon.

This high requirement for an expertise may have negatively affected the possibility of a widespread implementation, and was perhaps responsible for the publication of an in-depth manual on transformative education for those engaged in teaching using this model (Pugh, 2020), and for the involvement researchers exhibited in implementation in TTES model. In the literature, it seems that either the researchers themselves served as the implementing teachers (Girod et al., 2010; Heddy & Sinatra, 2013; Pugh, 2004), or the research was described as a close, deep and long process of guiding a teacher by a researcher (Heddy et al., 2017; Pugh, Bergstrom, Heddy, et al., 2017; Pugh et al., 2010).

After I was applying the model myself as part of an action research, and experienced the subtleties of its applications from a perspective of both a teacher and a researcher, it was my contention that a new model could be offered for implementation. A hybrid model in which the qualities of the TTES model will be expressed through an online unit on evolution, while the teacher, who will receive a mere perfunctory guidance regarding the model, will complete and strengthen the transformative learning process. Given the many signs attesting to a widespread growth of virtual learning in K-12 contexts (Short, Graham, Holmes, Oviatt, & Bateman, 2021; Staker, 2011), and the catching up of research with the migration of instruction from conventional to digital media (Mayer, 2019), offering an online hybrid implementation model seemed plausible.

This proposed implementation model warrants the design of an online evolution teaching unit that is based on the TTES model qualities (from now on referred to as “unit”). The challenges of designing such a unit lie with incorporating as much of the TTES model spirit in the design as possible, and with adjusting, refining and developing implementation methods and strategies suitable for the media. Since there was no report of a design of such a unit yet, there might be a possible value in such a unit’s contribution to the field. Using such a unit might free the researchers from the need to be heavily involved with close guidance all through the implementation. It might spare the teacher from deeply acquainting herself / himself with the philosophy the TTES model is based upon, and from the lengthy process of making adjustments to the teaching process according to the TTES model that is suitable for the teaching subject (e.g. scaffolding re-seeing by identifying objects suitable for re-seeing, or integrating students shared re-seeing experiences as case studies for the continued instruction), and to the way the teacher interacts with the students (e.g. modeling transformative experiences, or framing content as ideas), and continuously refining these adjustments. It might allow the teachers themselves to get acquainted with the TTES model gradually, while working with it, and to deepen their understanding through the iteration of a continuous experience. It might also allow access for large groups of students to the experience learning evolution through the TTES model.

The results of studies implementing the TTES model (Girod et al., 2003; Girod et al., 2010; Heddy & Sinatra, 2013; Pugh, 2004; Pugh et al., 2010) refer to the reported implementation models alone, which place the teacher as the source for initiating, creating and applying the transformative experience teaching model. Thus, in changing the medium that is responsible for motivating transformative experiences it is necessary to inspect the learning process and its results. It is imperative to assess whether learning through the unit would indeed motivate a transformation in the way students perceive the world, and to linger especially on evidence of all the aspects the TTES model is designed to involve, that is, the AU, EP and EV aspects. Evidence of transformation, if exists, could be used as proof of concept for using such a unit as a transformative experience medium, and might render a design research worthy.

Research Objective

Evaluating the influence of learning using the online evolution teaching unit, on the transformation and conceptual change process among secondary school biology majors.

Research questions and hypotheses

(Quest. 1) If and what transformative experiences will be reported by the learners of the online unit on evolution?

(Quest. 2) If and to what extent the learners of the online unit on evolution experience a conceptual change toward the scientifically acceptable model?

(Quest. 3) What are the characteristics of the learners conceptual change process while learning using the online unit on evolution progresses?

The prediction is that learning evolution using the unit would (1) initiate a transformation process, manifesting in a transformative experiences, (2) result in a conceptual change toward the scientifically acceptable conceptual model regarding biological evolution, and (3) be characterized by individual routes of conceptual change toward the scientifically acceptable conceptual model regarding biological evolution, with joined participant group's patterns.

METHODS

Research approach

The current study is a mixed method research of an applied research type, which combines a quantitative and a qualitative approaches (Creswell, 1999). Testing the effect of using the TTES model on students' transformation and conceptual change process regarding evolution, describes the effect of theory-based teaching on the learning process, and can therefore be characterized as deductive – "top down" (Creswell & Creswell, 2017). However, learning about the students' learning process by analyzing learners artifacts draws from the learning field to describe emerging patterns. Although the teaching model is rooted in theory, this research practice draws from the ground upward and can therefore be characterized as inductive – "bottom up" (Charmaz & Smith, 1996).

The need to assess the conceptual change for a variety of concepts over time, as well as the abundant data that was expected to be gathered by the digital medium, has tilted the scales practically towards the initial decision of using quantitative instruments to assess conceptual change and the change process. These instruments (questionnaires, a perception board) allow for valid repeating comparisons, resemble instruments that are routinely used in remote or hybrid learning classes, and allow for a large number of perceptions to be addressed simultaneously. This study used quantitative instruments to identify, gauge and describe conceptual change and various aspects of transformation using data gathered digitally. It is important to notice that in this study these instruments quantify experiences, emotions, and perceptions, thus enabling patterns that emerge from analysis to be cross referenced with qualitative emerging data pointing to the same issues. Qualitative instruments offer a complementary vantage point in this study, which help identify and reaffirm patterns and learning processes, validate results and deepen interpretation (Thornberg & Charmaz, 2014). In some cases, such as when the quantitative instruments are found lacking or provide results that are statistically deemed as unreproducible, the qualitative instruments (narrative analysis of student artifacts) stand as the main and sole assessment of conceptual change.

Due to the great attention this research would pay to the students' personal concepts evolvement process, there would be a direct preoccupation with the students' perception of reality that would be expressed in the student's perception of evolution as part of their everyday life. This notion of concept learning that enriches everyday life experiences and worldview is a fundamental idea of the TTES model (Pugh, 2011; Pugh & Girod, 2007). This study would implement the idea by identifying the different students' perceptions and by motivating the students to use them as building blocks for a widened perception of evolution. Consequently, the learning process stands to bare a constructive nature. Due to the comparison of students' perceptions to the acceptable scientific conceptual model, it seems correct to assume that this study maintains a positivistic approach, with a realistic ontological dimension that displays acceptance, tolerance and respect for the students reality perception processes. This approach is phenomenological. The phenomenology approach determines that truth is knowable through embodied perception, and that meaning is created through experience (Starks & Brown Trinidad, 2007). Since this research intends to learn about the meaning and value students assign to their experiences, of the way the students worldview expands due to content prism, and of their motivation to use the content from students' perceptions and learning experiences through the unit, the phenomenological approach seems to fit.

Research sample

The target population for this study consisted of 10^{th} - 12^{th} grade biology majors studying evolution as part of their biology curriculum. This research sample was gathered in a convenient sampling manner that consisted of students learning evolution with teachers within my acquaintance circle. The sample is considered as a typical case. The research sample that was originally sought for this study was comprised of four biology majors' classes of the aforementioned grades, from different schools, and of different regions in Israel. The research took place during the Covid19 world pandemic, hence the sample's size was affected by the consequences of the pandemic, namely by quarantines and isolations. These led to student's sporadic absences, and the research classes were falling behind on their curriculum due to the disrupted learning pace. That situation caused a delay in the implementation in the 10^{th} and 11^{th} grade biology majors classes, a drop in the number of students in the classes who did join the research, and to the dropping out of the 12^{th} grade biology majors class which was supposed to take part. The study's implementation phase started on schedule in March 2021, with only one of the classes. A second and a third class joined in April 2021, and May 2021, respectively. A summary of the planned sample and the actual one presented in Table 2.

Table 1 - The planned and actual research sample

School's City / Region In Israel	**Grade biology majors' class**	**Planned participants No.**	**Actual participants No.**
Gush Dan metropolitan area, a city in Tel Aviv District	11th grade	18	16
Jordan Valley Regional Council	10th grade	23	8
Tamar Regional Council, dead sea region	11th grade	12	8
The Negev desert, a city in the Southern District	12th grade	24	-

1 Table 1

This study is characterized by a phenomenological approach, hence the sampling includes participants who have experienced the phenomenon of learning evolution through the unit. The research follows the participants learning process through the unit in order to learn about their perceptions, and to identify, gauge and inspect those perceptions for possible transformative and conceptual change processes and their characteristics. This is done anonymously. Each student receives an idle number which functions as the student ID all through the unit. The reduced sample size does not hinder the objective of this research to explore the TTES model influence over participants who have experienced learning evolution through the unit. Unfortunately, the reduced sample size does interfere with the possibility to generalize the research findings.

Unit context

The evolution instruction sequence of the unit is derived from the eleventh-grade biology ecology curriculum content specification regarding evolution (Israeli Ministry of Education, 2015). The unit's estimated teaching time is of twelve teaching hours delivered in class or remotely, accompanied by ten asynchronized out-of-school hours of independent work. The unit's instructional sequence is presented in Table 1.

Table 2 - The evolution unit sequence

subunit	Content of the unit
1	Observing nature: "What do you see?" recognizing organisms' features, their way of living, and the environment they live in.
2	Organisms adaptation to the environment, and adaptation types. Definitions, identification, comparisons, and Out-of-school (homework) nature assignment.
3	Collaborative activity: "Does your beak make you freak?" Natural selection. The compatibility of an individual attribute and the environment influences: why do they look like that?
4	Industrial melanism: From statistical analysis to evolution mechanism - putting it all together. Virtual Moth Lab. Discussion.
5	Out-of-school (homework) nature activity: Variation. Discussion: variation and natural selection. Fitness. Group workshop: California Salamander: "ring species" concept: the creation of species. Summation.
6	Practice: "adding color with human evolution". Skin color's cellular mechanism. Skin color variation, prevalence, UV influence, extinction and the Handicap Principle, world UV map, human migration path. Values, civic engagement, relevance and evolution: Equal opportunities, and discrimination because of skin color in society. Crafting a position paper.
7	Evolution as a worldview: reflection on the road so far.

The sequence presented in Table 1 is an adaptation of the preliminary research evolution intervention instruction sequence presented in Table 1 of the attached article (Appendix E). The complete unit's structure, activities and work materials were converted in this study to a TTES model inspired online evolution teaching unit in the PeTeL system.

The TTES Model implementation design for the online unit

The TTES model's design principle of *modeling transformative experience* rely on teacher-student interactions, the *scaffolding re-seeing* principle rely on tendentious construction of the learning process to enable and practice re-seeing, and the *framing* *content as ideas* principle rely on displaying the disciplinary content through a specific reference framework. Using a digital form of teaching drives teachers to assume the roles of facilitators, thus narrows teacher-student teaching interactions (Harper, 2018), and by proxy the extent by which teachers' shared experiences may use to guide, model and motivate the TTES model qualities (AU,EP & EV). Since modeling transformative experiences is a vital design principal of fostering all the TTES model qualities (Pugh, Bergstrom, Heddy, et al., 2017; Pugh & Girod, 2007; Pugh et al., 2010), this situation called for finding new strategies to model experiences, that are compliant with the digital medium, as well as for finding other design principles and implementation strategies that will encourage AU, delineate EP, and prompt awareness and recognition of EV based on the digital medium strengths.

The unit uses a variety of teaching methods and means that were previously depicted by TTES implementing literature, that I have found suitable and typical for 10^{th} - 12^{th} grade biology majors classrooms, and to the specific pedagogic targets at hand at different points of the learning course: reading texts and stories, hands-on activities (lab work), media inspection (videos, newspaper), worksheets, interactive PowerPoint presentations, and discussions (Girod et al., 2003; Heddy & Sinatra, 2013; Pugh, Bergstrom, Heddy, et al., 2017; Pugh et al., 2010). Different unit's learning activities were designed for individuals, couples and groups, and were performed in an indoor and outdoor settings. All these teaching methods, means and settings were crafted to elicit the TTES model's qualities. The next paragraphs will lay out which design principles were used in the unit, and how they were used, which implementation strategies were used, and what were the considerations for their inclusion in light of the and TTES model.

Modeling transformative experiences – sharing instructor's personal AU, EP & EV

To model transformative experiences in the digital medium the unit's design recruits to its benefit the social cues based multimedia learning principles of personalization, voice, and image (Mayer, 2014). In congruence with the social cues principles, all the unit texts that share experiences, tell stories or present metaphors turn to the students informally, in a conversational direct style. Additionally, the unit embeds personal messages spoken in a human voice.

Modeling AU The first subunit opens with the units narrator's personal story of observing the *Cinnyris osea* birds that drink dripping water from the living room windowsill, and inadvertently putting themselves on display. The mentioned living room picture is presented. Sharing daily personal experiences from home anchors the evolution ideas, that are about to be learned, as possibly connected to daily life. When taken together with the question: *"What do **you** see?"*, that is referred to the students, there is a latent encouragement for students to examine their own home environment and daily lives for connections to learned ideas. The anchoring of learned ideas to daily life connects deeply to R. E Dewey's (2012) notions that call for the learning to be taken out of the class and into life's daily experiences (R. E. Dewey, 2012). The last subunit text reminds the students that they have "visited" the narrator's home, and re-shares and deepens the notion of the connection between the evolution ideas to every day's experiences. The narrators story is presented in both direct conversational style text and an audio authentic files. Beyond adhering to the social cue based multimedia learning voice principle (Mayer, 2014), the use of the audio messages allows for the display of authentic enthusiasm for "seeing the story of the species" in every *Cinnyris osea* bird.

Modeling EP The unit's introduction "talks" directly with the student, as a person, and presents evolution as nature's secret. Unveiling the secret might enable the students to "read" reality differently. This notion actually presents EP as the unit's goal: to expand perception so that nature is seen through the lens of the content of evolution. The introduction bring examples of people - researchers, biology teachers, scientists - who are "secret partners," namely, who see the world this way, and invites the students to be listed among them and take part in this worldview. It is mentioned that the students will be invited to share their worldview at the end of learning through the unit, thus keeping the students aware to the fact that they should pay attention to their worldview during learning, since they will be given the opportunity to share it. This students' awareness to their own worldview "lays it down" for examination. It is intended to encourage reflection on the purpose of the unit's learning process of actively engaging their authentic worldview, beyond making evolution knowledge accessible to them. The EP sharing is general and does not include specific examples.

Modeling EV The EV modeling is entwined through the entire unit. The unit's introduction shares the EV of people, who are presented as holding to an evolution worldview:

> *"Some feel tremendous respect and responsibility for everything that lives, some feel amazed and enjoyed by the wonderful complexity that envelops them, some feel a partnership of destiny with everything that lives, some appreciate the possibility of assisting the restoration of nature through its understanding and research, and some simply derive pleasure from nature enveloping them."*

The introduction text suggested that the students too may come to associate these values with their experiences in the world, should they take part of learning evolution with the unit.

The first subunit opens, as mentioned before, with the narrator's personal story of observing the *Cinnyris osea* birds that drinks dripping water from the living room windowsill, and inadvertently putting themselves on display. This story is accompanied by audio messages that share the narrator's thoughts and feelings. These personal audio messages model EV by expressing the narrator's enjoyment of both, the *Cinnyris osea* birds beauty, and the ability to "read" the story of the *Cinnyris osea* birds entire specie from closely observing them. These statements express the value that the narrator associates with the everyday experience.

A deliberate choice was made to use professional beautiful images of nature throughout the unit. The pictures were meticulously chosen to visually express ideas and intentions and to support stories atmosphere. There are many examples: the unit's introduction present a picture of a magical forest that appears to be calling the observer to unfold its secrets. Organisms are photographed next to beautiful flowers and appear to curiously look at the first units question of "*what do you see?"*, and in the statement of "*we learn to "read"* ". The second subunit presents the student with large close-up pictures of organisms in their natural environment, for the adaptation recognition exercise, the perception questionnaire is accompanied by a picture of diverging roads in a forest, and there are many more. Three ideas led this new strategy of using such vivid expressive pictures: (a) drawing attention to the aesthetic aspect of the learned ideas, (b) intensifying the sense of connection to nature that students are asked to explore, and (c) enhancing the learning experience itself, using the advantages of the digital medium.

There are established perceptions that link cognitive, rational ways of understanding to aesthetic ones. These perceptions strive for a deeper, more holistic understanding that include an aesthetic aspect (Girod et al., 2003; Girod et al., 2010; Pugh & Girod, 2007). The deep perception of art and beauty, especially of nature, is intimately connected to experiences of the world. Exposure to art and the beauty of nature is perceived to intensify the sense of connection to nature, and are considered beneficial for achieving a new view of the world, and an appreciation for the intricate scientific processes that create it, and operate in it (Pugh & Girod, 2007). Allowing Art, beauty, and aesthetics to take part in science learning is thought to integrate misrepresented or overlooked important aspects of science learning (Girod et al., 2010). Based on these presented ideas my contention was that using this new strategy will allow for the modeling EV design principle adaptation for the digital medium.

The unit also draws attention for the possible use and value of the ideas/content of evolution might have in the students' life experiences. At the very end of subunit six, the students analyze a T.V. report, and a magazine clipping on racial discrimination. They are presented with the law, requested to draft a position paper on the subject, and to use the evolution ideas they have learned as a basis for their arguments. Since unfortunately racial discrimination is still very present in society, this example models the usefulness and value the learned evolution knowledge might play in the students life.

Scaffolding re-seeing – structuring and escorting the perception evolvement process

The process of re-seeing is gradual. It is not a process of learning a complete abstract theory and then examining its interactions with reality, but rather a continuous repetitive interaction between the ideas studied and the evolving worldview, which moves in a non-linear trajectory. Scaffolding a complex process such as re-seeing is challenging even when teacher-student face-to-face interaction is the main teaching medium, that enables the teacher to change her/his reaction in adaptation to the student's evolving perceptions. Designing re-seeing scaffolding for an online unit that is a final and closed product suited to every student is even more challenging, and requires the admission of ideas such as flexibility, repetition and gradual advancement in its' planning. Therefore, the unit utilizes the flexibility that the PeTeL platform offers for the learning process; it includes diverse means of learning for the same content that enable both repetition and the connection of different students to the learning process; and it breaks the evolution learning process into small consecutive steps that allow for gradual and personally paced advancement, while leaving room for teachers to outline the way, and to intervene. Another unit's attribute to note is that the subunits' content sequence itself may be regarded as a conceptual structure for scaffolding an evolutionary worldview, thus expressing the principle of re-seeing. The implementation strategies for scaffolding re-seeing is hereby presented.

Locating objects and opportunities suitable for Re-seeing practice
(Pugh, Bergstrom, Heddy, et al., 2017)

The unit's moto is "*we learn to "read"*", which actually stands for "we learn to re-see". Re-seeing reality demands for not taking the immediate observation for granted and re-examining the objects and processes, in "new eyes" searching for a deeper understanding (Pugh & Girod, 2007). Every subunit refers to this "reading", and actively creates the opportunities to re-see by asking the students both to "read" and to notice whether their "reading ability" changed. By doing so the unit expresses yet another strategy that is known for scaffolding re-seeing: ***estimating how an idea or an experience changes and widens the perspective*** (Heddy & Sinatra, 2013; Heddy et al., 2017)

The objects are either beautiful organism pictures presented by the unit, or an organism independently chosen by the students. This reading metaphor evolves along the unit. For example:

in the first subunit, there are pictures of *Cinnyris osea* birds and the question: "*Every organism holds the story of its entire specie, and of all species. We learn to "read" it. what do you see?*"

in the third subunit, the observation assignment of organism and their habitat is accompanied by the question: "*we hope that you will "see" the animals somewhat differently, have you ever deeply observed an Owl/a Capra/a Cyclamen?*". A re-seeing exercise is embedded among hand-on activities: "*Select an organism that interests you. We'll try to see it all over again. "Read" it. It's story, and the environment its' population live in. Take a closer look at the organism or its images. What do you see? Are the adaptations of the organism visible? What have you observed? Can you speculate from the adaptations what is its' life's environment and its' population's environment* ?". The last exercise question to answer in the third subunit is: "*how did this activity influence on your ability to "read" the story of the specie, by observing the organism*?"

an exercise in the fourth subunit is opened with the statement: "*Now you have a wide infrastructure for "reading" the organism. An infrastructure that may lead you, as it has led many before you, to see organisms differently*". This exercise asks the students to choose an organism and a phenotype, to analyze how that phenotype might have contributed to the organisms' fitness in a certain environment, and to speculate about the selection pressures that might have led to the evolvement of such a phenotype.

Using students reported experiences as case studies for advancement

(Pugh, Bergstrom, Heddy, et al., 2017).

The unit is built to incorporates the student's responses as learning resources. This is achieved by fragmenting the learning process of every subunit to consecutive steps that refer to one another. The unit addresses the students to share their experiences and perceptions in writing before, during and after every learning experience, such as an experiment, a simulation, video analysis, and so on. The directive also include an invitation for reflection, that is done individually and as a group, thus entering an element of social learning to the re-seeing process. For example the observation activity of subunit two is fragmented into four sub activities. The first is done in teams and involves making an elaborate observation and re-seeing report of a self-chosen habitat and it's organisms. The second is done individually and involves deepening the report with emphasis on a specific organism, the third is taking part in a creation of a joined activity - the contribution of a personal slide for a class presentation. The student shares an organism's picture with the class, that is directed to "read" the organism, in a discussion led by the student. The forth is a class discussion of the question: "*How were all these unique traits for each species created?* ".

Frame content as ideas – presenting the content as a possibility to explore in an everyday context

Nurture evolvement of thought and understanding

When exploring an idea as a possibility, any hint of an expected specific outcome for this exploration immediately eliminates choice from the process, and renders it moot. Thus, framing content as ideas calls for deliberately accepting the student's opinions as legitimate, without judgment of their accuracy, but rather as a basis for scientific inquiry in accordance with the nature of science. Appraising the learning process itself rather than the outcome, also supports this notion. This strategy aligns with the encouragement for teachers to receive students' initial attempts to reach a transformative aesthetic understanding in a nurturing way (Girod et al., 2003). Hence, the unit, especially when comes to evolution mechanistic ideas, does not present ideas as absolute truths, and does not correct opinions. It does, however, openly ask the students to share their authentic opinions, in a distinctive goal of creating a sharing atmosphere, offers platforms to debate conflicting ideas in a group, and constantly revisiting prior ideas in new contexts. For example, even approaching to the end of the learning process, subunit six, dealing with human skin colors poses the question: "*What factors will affect the skin color of the human population in the future to your opinion?, please explain your answer*", three times repeatedly during the unit, with the added wonder: "*Has my mind changed?*". This strategy is very present all through the unit.

A sense of wonder about the potential of artful and compelling ideas

(Girod et al., 2003)

This strategy drives teachers to ask students to be more imaginative and creative when contemplating an artfully presented content (Girod et al., 2003). This strategy expresses itself in the unit, in the direct request for creativity, especially when encountered by a question that is meant to stir the imagination or thought, usually accompanied by a request for a hypothesis as a learning product. For example at the end of a joined discussion about a possible mechanism that could have create adaptation (the question that was meant to stir the imagination or thought), the students were asked to offer a personal hypothesis, and were mentioned: "*Try to imagine such a process in your head. Remember, you are not required to be right. Only creative.*"

Use the word "ideas" instead of knowledge, concept or truth
(Heddy & Sinatra, 2013)

This strategy is really very simple. Since words are symbols that enfold meanings that are constructed in the mind (Linder-Pelz & Hall, 2007), when we strive for students to think of content as ideas, we should constantly refer only to ideas. Some examples: "*…after it the* ***idea*** *of Ring Specie will be presented… …we will discuss our* ***ideas*** *on the matter…*", "*thinking, expressing an opinion… enjoy thinking and may you have new* ***ideas*** ", "*In this subunit we will reflect – what was the influence of the learning and the* ***ideas*** *over me?*".

Compelling metaphors - metaphors as generators of anticipation
(Pugh, Bergstrom, Heddy, et al., 2017)

The unit uses a strong metaphor: nature enfolds a secret. The secret is hidden in plain sight for everyone to see. However, in order to see the augmented reality layered with the meaning of the secret, we need to learn to read it. the secret is that every organism holds the story of its entire specie, and this story even relates to the story of all the other species. This strong metaphor generates anticipation to develop the skill of reading that is needed to unfold the secret. In the case of the unit, the meaning is of course seeing the world through the lens of evolution. This metaphor goes all through the unit. As the learning process advances the vail becomes transparent, and at the end nature secret is clear and the student is asked to evaluate its influence:

" *At the beginning of your learning process, you wondered what secret nature enfolds?... …I've shared with you how my understanding of evolution permeates to the way I see everything around me and enriches my world… …You have learned to look and observe carefully, in depth, differently, and to notice the things that have allowed you to "read" reality. You've learned to "read" organisms. You've studied evolution. Now you can see nature in "Evolution Goggles". How does this view affect your worldview? What do you take with you from this process? Will it accompany you on?* "

Practice at the student's personal life environment

(Heddy & Sinatra, 2013; Pugh et al., 2010)

This is not a TTES model known principle or strategy. Nevertheless, it was used off-hand in research when students were taken to the zoo to assess their engagement (Pugh et al., 2010), and also in a research in a form of nonobligatory request to search for evolution concepts in their everyday environment (Heddy & Sinatra, 2013). Since environmental contexts can serve as retrieval cues for events that occurred in those contexts (S. M. Smith, 2013, p. 177; S. M. Smith, Glenberg, & Bjork, 1978), I hypothesized that practicing out-of-class, at the student's personal life environment may present an opportunity for students to tether learned perceptions to their life's experiences and surrounding. This environmental cues may lead students to actively use the evolution ideas in their everyday life, as well as to reflect on the value these ideas have in their everyday lives.

The unit offers divers opportunities for the students to practice in their personal life environment. Some of the opportunities are hands on activities like performing and analyzing observations (subunit 2), conducting home experiments (subunit 3), and testing for variation (subunit 5), some involve homework of picking everyday life objects for re-seeing, and other opportunities arise from using hybrid learning that leads to performing some of the unit mediated learning at the student's personal life environment.

Teaching Process

The teaching process was administered by teachers, who were not familiar with the TTES model, and were presented with the TTES implementation strategies for the first time. The teachers saw the unit prior to teaching the subject, and were given a personal technical instruction for operating it, as well as the opportunity to work through the unit as students. The teachers were encouraged to communicate with the students using the same strategies employed by the unit. This means creating a sharing environment in the classroom, by verbally encouraging to bring real-life examples to class *("It's lovely that you have brought to class the concept of... that you thought of at home")*, and setting personal example by sharing the meaning knowing and understanding evolution bears with them. It also means sharing relevant experiences from their own life on the subject, and fostering a judgment free environment, in which it is safe for students to articulate ideas, to share extra-school experiences and to convey the way they see the world.

The teachers taught using the unit, whether at a physical class or a digital class at a distance, while students worked through the unit either directed and supported by the teachers, or independently in class or at home.

Unit online platform

Teaching the evolution subject in class, while using the unit as a teaching measure in class and/or at home, could be characterized as hybrid learning (Staker, 2011). In that form of teaching, the teacher integrates the different online and offline learning activities to guide and support the students' learning process. It is important that the Learning Management System (LMS) in which the unit is embedded, would support hybrid learning by supplying continues information regarding the students' progress to the teacher.

The online platform that was chosen for this research's online evolution teaching unit is the Personalized Teaching and Learning (PeTeL) platform. The PeTeL platform is a computerized online Moodle based LMS aimed to achieve personalized teaching in the classroom, whether the classroom is a physical or a virtual space. The PeTeL platform fits the current challenging times that require flexibility regarding the teaching medium. It also fits the transformative teaching model by allowing personalized learning experience based on the concepts each student holds. This differential treatment applies to groups too. The

PeTeL platform can be used in different ways to accommodate different classroom needs, at the teacher's judgment, and was evident to be used as such (Aviran, Easa, Livne, & Blonder, 2020). These perspectives drove my decision to use PeTeL as the platform for this research's online evolution teaching unit.

Instruments and data analysis

All instruments in the current study are digital instruments that will enable monitoring the participants' personal and group's concepts, conceptual change patterns, as well as transformative experiences.

PB – the Perception Board

To continuously follow students' perceptions before, during and after learning through the unit, I used a perception board. This instrument monitors individual and group patterns of conceptual change toward or away from the scientific perspective of evolution. The perception board framework was adopted from Shtulman's evolutionary reasoning scale (Shtulman, 2006). The scale was used to assess whether participants understood evolution and its various phenomena (adaptation, variation, domestication, etc.) as a transformational or variational change (Table 2). As noted in the introduction, a transformational change is a view of evolution which maintains that species possess an inherent essence, which transforms over time. Various alternative conceptions stem from this view, among them, inheritance of acquired traits, and adaptation led by internal intent. A student who holds a transformational view of evolution may believe that an organism adapts to the environment by changing its traits and that said changes will be passed on to its offspring. A student who holds a variational view of evolution understands that species change through random gene mutations which, over time, cause variations in the population through natural selection. Each view presents an inherently different conceptual understanding of evolution: the variational view is consistent with the scientific perspective and the transformational view is inconsistent with it. In accordance with Shtulman (2006), Heddy and Sinatra (2013) also used this framework to analyze students' survey responses. In contrast, I used this framework to present the students with contradictory views of several evolutionary phenomena, and asked them to continuously evaluate and present their view of each phenomenon.

TABLE 3 - Variational (V) and transformational (T) interpretations of the same evolutionary phenomena. Processed from Shtulman (2006, p. 175)

Concepts	Phenomenon	Theory	Interpretation
A	Variation	V	Individual differences are fodder for selection
		T	Individual differences are minor and non-adaptive
B	Inheritance	V	A trait’s heritability depends upon its origin
		T	A trait’s heritability depends upon its adaptive value
C	Adaptation	V	Differential survival/reproduction produces adaptation
		T	Differential survival/reproduction is irrelevant to adaptation
D	Domestication	V	Species are domesticated via selective breeding
		T	Species are domesticated via changes to individual organisms
E	Extinction	V	Extinction is more common than adaptation
		T	Adaptation is more common than extinction
F	Speciation	V	All species share a common ancestor
		T	Closely related species share a common essence

The contradictory views were placed on opposite sides of a board. Each side of the board included interpretations that represented the variational theory—which stands in line with the scientific view of the phenomenon, and interpretations representing transformational theory. The space between each pair of views was divided into five segments, creating a scale. The students were asked to choose a number on that scale (1-5) as a representation of their perception regarding the views on the board. The students were made aware that they were being appraised for their mere participation, and not their choices, and were urged to express their real opinion even if they thought the teacher expected a different one. This process is repeated eight times, in the unit’s introduction, and once at the end of every unit, for a representation of the change in student’s perceptions over time.

The perception board assessed six characteristics of evolution: adaptation, variation, inheritance, domestication, extinction, and speciation. These aspects were chosen because they have been found to be imperative to the understanding of biological evolution and to underlie the cognitive bias of essentialism, which is manifested in many alternative conceptions (Heddy & Sinatra, 2013; Shtulman, 2006; Shtulman & Calabi, 2012). The concepts of adaptation and variation were addressed directly in the unit as major subjects, the concepts of speciation and extinction were taught as minor subjects at the unit, and the domestication and the inheritance concepts were not dealt with at all in the unit and were left for reasons of comparison, and for not harming the measure's integrity and validity.

The perception board data, which was in line with the scientific perspective of evolution, i.e., the variational view, was assigned a value of 5, whereas an entry which was fully inconsistent with the scientific perspective of evolution, i.e., the transformational view, was assigned a value of 1. Since the students could position their responses on any of the five scale segments on the board, the numerical value varied between 1 and 5 for each evolution characteristic. Each numerical value was assigned to a student and to a specific date. The analysis included variable frequency calculations (repeated measures analysis of variance [ANOVA]), mean comparisons between the first and last board entry using the Wilcoxon signed-rank test to ascertain significance, and Duncan's multiple range test to assess whether the last entries differed significantly from early entries, thus pointing to conceptual change.

In order to use the PB for analyzing the concept's perception evolvement process of an individual student, I prepared a visual representation that integrated all the scores each of the student's PB entry for every concept received, in all subunits. In this graphic figure the X axis stood for the subunit's number, thus flexibly representing the student's learning progression. The Y axis stood for the value assigned to the student's entry according to her/his perception of the evolution concept (between 1 and 5 as explained in the previous paragraph), thus reflecting whether the concept is perceived in a scientific accepted way (i.e. variational) or in an alternative way (i.e. transformational). Every concept (presented in Table 2) was portrayed by a different color. The entries were represented by dots, and were joined by full lines to ease the grasp of a concept perception evolvement process. The perception evolvement of a concept is not linear. Perceptions change during learning. Assessing whether the overall trend of that change is away from or toward the scientific view of the evolution concept might be challenging. In order to contribute to a better understanding of the perception evolvement trend, I added a trendline for each perception evolvement process. This trendline appears in the graphic figure as a dotted line in the same color of the concept it represents. This visual representation makes it easier to refer to a student's complete perception evolvement process regarding a specific evolution concept, and to cross the data interpretation with other measures for a more complete analysis.

ERS – the Evolution Reasoning Scale

The Evolutionary Reasoning Scale was developed by Shtulman (2006) for the purpose of assessing conceptual knowledge regarding evolution. I used this survey to assess the extent to which participants understood evolution as transformational or variational change (Table 2 presents the opposing views). While a variation understanding of evolution is considered consistent with the scientific perspective, the other one does not. The Evolutionary Reasoning Scale much like the Perception Board assessed knowledge on six characteristics of evolution: adaptation, variation, inheritance, domestication, extinction, and speciation (Shtulman & Calabi, 2012). (see Appendix B for the complete survey).

This instrument includes 14 closed-ended questions. Responses were considered correct when they were consistent with the scientific perspective. Responses were given a value of (1) when a response who is in line with the scientific convention and (–1) when it is not. The score ranged (14) to (-14). A negative score represented the misconception view of evolution, and a positive score represented the scientific view of evolution. Therefore, a change in score from negative to positive was considered as evidence of conceptual change (Shtulman, 2006). The ERS was administered twice in the unit. The first time in the introduction as a preliminary measure, and the second time at the end of the fifth subunit. I chose not to administer the ERS at the last unit since I wished to refrain from large number of results achieving maximum scores, also known as a ceiling effect (Schweizer, 2016; Schweizer, Ren, & Zeller, 2019).

The Cronbach Coefficient Alpha turned out to be of low value for both, the ERS taken in the unit's introduction (ρ_T=0.226121), and the ERS taken in subunit five (ρ_T=0.433836). Examining the Cronbach Coefficient Alpha value for subgroups of questions in the tests according to the evolution's phenomena presented in Table 2 produced similar low valued results.

TES – the Transformative Experience Survey

This instrument was used to measure students' engagement in transformative experiences after learning evolution using the online evolution teaching unit, thus enabled to estimate the unit's ability to foster transformative experiences. It includes 20 Likert-scale items and 3 open-ended questions adapted from an instrument developed by Pugh and his colleagues (Pugh et al., 2010) for the specific topic of the present study, and was also used by Heddy & Sinatra to that purpose (Heddy & Sinatra, 2013). TES statements were divided into categories expressing different aspects of the TTES model qualities: (1) active use (AU), (2) expansion of perception (EP), and (3) experiential value (EV) (Pugh, 2011; Pugh & Girod, 2007). Statements 1-9, refer to using the evolution ideas in an out-of-class, everyday setting, expressing the AU aspect. Statements 10-14, refer to the students possibly changed worldview, expressing the EP aspect. Statements 15-20, refer to value assigned to the evolution ideas and learning about them, expressing the EV value. This study repeats the way in which this survey was performed and analyzed before (Heddy & Sinatra, 2013; Pugh et al., 2010). The survey was administered at the end of the unit, as the last exercise. The Participants were asked to agree or disagree with each statement using a 6-point scale ([1] strongly disagree to [6] strongly agree). (See Appendix C for the complete survey).

The survey's reliability was assessed using coefficient alpha (Cronbach's α). The TE Survey three open-ended response questions provided further insight into the types of experiences engaged in by participants and represented by the AU, EP, and EV model's qualities as well. The responses were used as material for the qualitative analysis and testified to the degree of the participants transformative experience. The open-ended responses were scored on a four point scale coding scheme in line with the TTES model qualities. The AU response analysis scale related to the environment in which concepts were reported to have been mentioned ([0] no response or an incoherent response, [1] uses concepts only during lessons, [2] uses concepts outside of lessons time but did not elaborate, or [3] uses concepts outside of lesson time and provided an elaborate example). The EP response analysis scale related to the estimation of change in the participants experiences ([0] no response or an incoherent response, [1] experience did not change, [2] general statement but did not elaborate, or [3] provided an example). The EV response analysis scale related to the value the participant found in learning evolution and in the evolution idea ([0] no response or an incoherent response, [1] do not find value, [2] general statement of importance or value, or [3] stating a specific value). The scores were analyzed for all three qualities and tallied for an overall degree of transformative experiences engagement. Five independent raters scored the open-ended questions. The interrater reliability was assessed by calculating the general agreement percentage, the specific agreement percentage, and Kendall's concordance coefficient (Siegel, 1988) for the specific agreement. Two independent raters were considered in general agreement when both independently scored an answer that attests to a positive or a negative meaning the same. For example, two raters that would score the same answer 0 by one rater, and 1 by the other, will be considered to be in general agreement but not in specific agreement. All raters final scores were averaged and used for analyses. For the complete survey see Appendix C. The TES opened items independent inter raters (n=5) agreement percentages and Kendall's concordance coefficient along with p values are presented in Table 4. The reliability was found to be relatively high.

Table 4 - TES opened items independent inter raters agreement percentages and Kendall's concordance coefficient (n=5)

Independent inter-raters agreement (n=5)					
AU response analysis		EP response analysis		EV response analysis	
General agreement of percentage	Specific agreement of percentage	General agreement of percentage	Specific agreement of percentage	General agreement of percentage	Specific agreement of percentage
97%	96%	99%	95%	98%	88%
Kendall's concordance coefficient values for independent inter-raters (n=5)					
AU response analysis		EP response analysis		EV response analysis	
W	p	W	p	W	p
0.91958	$4.0516E^{-12}$	0.92410	$3.3149E^{-12}$	0.75056	$6.1097E^{-9}$

The results of the statements evaluation are analyzed statistically, for the whole survey and for each TTES qualities apart. The statements are scored on a scale between 1-6, thus any average value above 3.5 indicates reports of more transformative experiences, and any average value below 3.5 indicates reports of less transformative experiences. The open ended questions were evaluated by 5 independent raters, on a 0-3 scale according to the extent of the transformation expressed by the student answer for each TTES quality. When 0-1 score points to an answer that does not express transformative experience, 2 score points to a generally expressed report of transformative experience, and a 3 points score to a transformative experience that was explicit or accompanied with an example suited for the TTES quality involved. The raters scores were averaged for each student and each question representing a TTES quality. This means any result above 1.5 is indicative of more reported transformative experiences, when higher scores are indicative of more explicit answers.

The Tau-equivalent reliability test was exerted over the whole TES 20 statements, and for the statements of transformative qualities categories separately. The Cronbach Coefficient Alpha results that are presented in Table 5 demonstrate high reproducibility for the TES results as a whole, and acceptable reproducibility values for the transformative qualities categories, rendering reference to the TES results as a whole as well as reference to the TES separate categories, sensible.

Table 5 - The Cronbach Coefficient Alpha results for the TES

	statement number	Cronbach Coefficient Alpha (ρ_T)
AU category	1..9	0.83
EP category	10..14	0.76
EV category	15..20	0.86
TES total	1..20	0.92

The mean difference between classes that took the TES was found to be insignificant. This assessment was reimbursed by the Duncan's Multiple Range Test results, when exerted for each class average of the TES results both as a whole, and segmented by the TTES model qualities, thus allowing for the inspection of the complete data set as one.

Narrative Analysis

All students were not recognized, and were referred to by an arbitrary number that was assigned to them by the PeTeL platform.

Deductive analysis

All students' answers and references to every subunit’s activity were collected and sorted into a table that created a textual chronological sequence of each student's activity in the unit. Since one purpose of the narrative analysis was to identify conceptual change, it was important to examine the students’ perceptions as reflected by the students answers, and to follow possible changes in perceptions as the learning progresses. The continuum of evolution teaching in the unit leads the student from identifying and assessing adaptation to the environment, through selection as a device that acts on the different features of organisms according to their fitness, then goes through the creation of species, and concludes with a complete practice of the evolution process.

In examining the students’ products, an attempt was made to identify the perceptions that deals with important concepts for evolution’s understanding (such as diversity, natural selection, adaptation, and fitness) and with the evolutionary process, that are characteristic for the learning stage. For example, the beginning of the unit that deals with observing organisms, their environment and identifying adaptation to the environment, the student's perceptions concerning the relationship between the organisms’ features and the environment’s characteristics, in which the organism lives and acts, are examined. In the subunit dealing with natural selection, it is examined whether the students' answers indicate any perception of fitness, and what is the perception expressed in their answers concerning the very process of evolution. In the subunit dealing with industrial melanism, the answers are examined for perceptions concerning the understanding of the nature of the evolutionary change, specifically, whether the nature of the evolutionary change is perceived as a change of an individual or of a population. The perception of permanence of an individual's features was also examined, thinking that recognition of evolution coincided with the notion that the features of an individual are fixed during his’/hers’ lifetime, are a steppingstone toward understanding evolution as a change in the population level, rather than in the individuum level. In the subunit dealing with variance, the answers are examined for perceptions concerning with the understanding the variance concept and whether and how the student links the population’s variance to the evolutionary process. The last subunit that contains pedagogical content and deals with skin color mechanism in regard to human evolution is actually a summary unit that binds all that is studied together and therefore all former perceptions are tracked. It is important to note that every perception was referred to, even if appearing in a none expected location at the unit. Every perception of the students was evaluated according to its similarity to the scientifically accepted concept, in a dichotomous nature (identical / different). My impressions of the all the unit’s students’ perceptions were written, and cardinal observations were emphasized. At this stage, an individual examination of each student's perceptual evolvement was conducted, and by the end of it, my impression of the student's perceptual evolvement was written, as well as a dichotomous assessment (yes / no) regarding the detection of a perceptual change towards accepted scientific concepts. During deductive analysis, should an answer appear to be identical to another students answer, it was mentioned in the analysis, and the identifier number of the student with the matched answer was mentioned.

In the seventh subunit, before asked to fill the research questionnaires, the students were asked: “*Now you can see nature through the "Evolution Goggles". How does this view affect your worldview? What do you take with you from this process? Will it accompany you further?*”. If the response included a reference to evolution content knowledge, then it was analyzed as the other perceptions in the unit, in regard to the accepted scientific concept. If there was a reference to the effect of learning and ideas on the students’ worldview, then the students’ response was analyzed according to the principles of the TTES. The analyzation results of the closed and open TES were added to each student's narrative summary file, with the thought of evaluating and weighting it, combined with the textual response to the subunit’s seven questions, to possibly determine whether there have been a transformation in the student's worldview regarding evolution (yes / no).

Inductive analysis

During the performance of the deductive analysis, I sometimes encountered a distinction that was not directly related to the analysis framework I performed. This distinctions were written at the end of the analysis document. After completing the deductive analysis, I reviewed the notes in order to examine whether they can be associated with the specific analysis framework I used. Comments that could not be specifically associated with the analysis framework that have been used, served as an independent inductive framework for examining the texts. All student products, including all impressions I wrote of the students' answers, have been examined with new eyes in light of these comments, in order to meet the scope of the phenomenon they represent. The impressions of this analysis was written alongside the comments and is presented in the results section alongside textual evidence.

Data screening

Data were unevenly screened among different measures. Not all participants' information was used. Due to numerous absences of students for reasons of illness or isolation, the school in a remote Kibbutz joined the study only towards the end of school year (May 2021). The eight participants from this school did not get to work through the unit further than subunit five, before the school year ended. This resulted in partial completion of the unit’s measurements. The students of this class did not take the TES questionnaire, which was to be filled out in subunit seven, and also took only some of the Perception Board’s questionnaires. The ERS questionnaires were filled out by the participants of the school in that remote Kibbutz, in both the introductory unit and at the end of subunit five. Participants from other schools completed the unit, except for sporadic absences of students. These absences resulted in them taking only some of the unit’s questionnaires and led to the withdrawal of the missing participants’ data from the questionnaires’ analysis. Furthermore, the questionnaires’ time stamps were tracked. Several participants worked through the unit in a non-linear way, and filled out the questionnaires in an unchronological manner. The data of these participants, if included, were to detract from the obtained results reliability, thus were omitted from analysis.

The TES questionnaire of the seventh subunit examined the data of twenty three participants (n=23). Of the 32 participants in the research sample, 8 from the school in the remote Kibbutz did not fill out the questionnaire at all, and one other participant was absent.

Many of the participants filled out only one of the two ERS questionnaires, and their data were removed. In addition, the analysis omitted the ERS data of two participants, who filled out the ERS preliminary questionnaire (pre-) after the interim questionnaire, for their results would not reliably reflect the learning process through the unit. Therefore, the ERS questionnaire analysis has taken into account n=16.

The perceptions board questionnaire was repeated eight times during the unit. Once in the introduction and at the end of each subunit. As such, it was reasonable to estimate the development and change of the participants' perceptions even in the absence of one or two Perception Board questionnaire results. In examining the Perceptions Board, all participants' results were taken into account.

No data were disqualified or omitted merely due to the results. All the data was used for the narrative analysis.

Unit's completion statistics

Student engagement with learning materials and activities during an online course is evidently an indicator to the success of learning processes (Soffer & Cohen, 2019), thus estimating the students completion of the unit activities would attests to their learning through the unit, and allow us to evaluate the derived unit's influence more accurately. In this study I estimated the students' actual involvement with the unit by examining the completion of the unit's learning activities. This means, counting the number of completed answers to every question of every unit's activity not including research questionnaires, and calculating the completion rates by dividing it to the total the number of questions. This rate represents the level of active participation. It is important to note that not all the classes that participated in this study completed the unit, due to systemic considerations and time constrains as previously described by the paragraph dealing with the research sample. For students belonging to a class that partially completed the unit, the completion rates were calculated out of the expected activities completion. This means, counting the number of completed answers to every question of an activity in the unit, until and including subunit five (not including research questionnaires), and calculating the completion rates by dividing it to the total the number of questions the unit presents before the students until and including subunit five. Furthermore, the completion rates mean difference between students who the narrative analysis found to hold the scientific view of evolution, and students who were not found to hold the scientific view of evolution, was tested by the parametric T-Test and by the nonparametric Kruskal-Wallis Test to assert significance.

Analyses software

All data descriptive statistics, and advanced statistical analyses were conducted using SAS 9.4 software.

RESULTS

I sought to explore the influence of learning using the unit, on the transformation and conceptual change process regarding evolution among secondary school biology majors. Specifically, I wished to measure the transformative experiences of learners (Quest. 1), as well as to assess the conceptual change toward the scientifically acceptable model associated with using the unit (Quest. 2). To address the first research question, I provide a picture of the transformative experiences by presenting quantitative and qualitative survey results. To address the second research question, I present quantitative summation of the narrative analysis results, that include reference to the units completion rates, as well as qualitative data from the units artifacts. To address our third research question of characterizing the learners' possible conceptual change process while learning using the unit (Quest. 3), I provide an integrated view of both the quantitative and the qualitative data to discuss the learning, the learning process and the conceptual change outcomes associated with learning evolution through the unit. The results are presented in light of these research questions.

If and what transformative experiences will be reported by the learners of the online evolution teaching unit?

To address the first research question, I analyzed the results of the Transformative Experience Survey (TES). This survey contains 20 statements and 3 open ended questions. Each of the TTES model qualities (AU, EP & EV) is represented by a number of statements and one open questions. The results of the statements evaluation are analyzed statistically, for the whole survey and for each TTES qualities apart. The statements are scored on a scale between 1-6, thus any average value above 3.5 indicates reports of more transformative experiences, and any average value below 3.5 indicates reports of less transformative experiences. The open ended questions were evaluated on a 0-3 scale according to the extent of the transformation expressed by the student answer for each TTES quality. This means any result above 1.5 is indicative of more reported transformative experiences, when higher scores are indicative of more explicit answers.

The descriptive statistics of the TES scores presented in Table 6, shows a positive inclination toward transformation, in the EP aspect of the transformative experience and no such inclination in the AU and EV aspects of the transformative experience, or in general.

Table 6 - The Transformative Experience Survey's descriptive statistics

Students n=23	Statements 1..20	Statements 1..9	Statements 10..14	Statements 15..20
	TES	AU	EP	EV
Average	3.454	3.459	3.661	3.275
SD	0.931	0.958	1.086	1.18

When exploring the TES statements results it seems that six statements out of twenty, received a score higher than 3.5 (3.96 - 4.83). The TES statements were:

"*During this study I talked about the evolution ideas I have learned*" (AU1),

"*During this study I thought about the evolution ideas*" (AU4),

"*During this study, I thought about the research evolution ideas differently*" (EP10),

"*The evolution ideas changed the way I view situations*" (EP11),

"*I think about experiences differently now that I have learned these evolution ideas*" (EP12),

"*I found it interesting to learn about the evolution ideas*" (EV15).

These statements tell the story of students who are influenced by learning with unit: they find interest in learning the evolution ideas, they talk and think about the evolution ideas they have learned, and the learned ideas influenced the way they view situations and experiences. Seemingly, since all three TTES qualities are involved, this story portrays a transformation process. However, it seems from other TES statements, especially statements dealing with initiating using the learned ideas in everyday experiences, as well as recognizing the contribution of the learned ideas to interest in life or books and movies, that there is still a way to go.

Yet, the TES statements only tell a part of the story. Table 7 presents the average scores for the TES open questions of all the transformative experience qualities, and the number of students out of N that are scored as expressing the presented quality of the transformative experience.

Table 7 - TES opened questions average scores and the number of student reporting an experience scored as expressing a transformative quality out of the N student taking the TES (n=23)

TES Question number	TTES quality	TES opened questions average scores [0-3]	Number of students reporting an experience, that is scored as expressing a transformative quality / n
Question 21	**AU**	1.774	13/23
Question 22	**EP**	2.061	15/23
Question 23	**EV**	2.217	19/23

All TES opened questions average scores for each of the TTES qualities are indicative of transformative experiences. Taken together, especially when considering the number of students involved, they represent evidence for transformation. For example, when answering the question "*Give an example of how your experiences have changed due to learning the evolution ideas*", a student answered: "*I saw a rabbit in the Kibbutz, and immediately thought about the adaptation of its fur and teeth to the environment it lives in*". This answer was unanimously scored [3], since it clearly presented an example of a changed experience. This answer was given for a question dealing with the EP quality, but when we take a closer look, it is easy to notice that the answer expresses thinking about an evolution idea (adaptation), in an out-of-school everyday environment for the student, and that this thinking was self-initiated, thus also expressing the TTES qualities of AU.

The apparent incompatibility between the results of the two parts of the TES (the first part does not point toward transformation except for the EP quality, while the second part does), led me to perform an individual comparison between the results of the two parts for the same TTES qualities for the same students. That means to compare all the cases in which the first part of the TES scores for a specific TTES quality showed evidence of transformative experience, or lack thereof, while the scores for the other part of the TES (the TES open questions) relevant for that specific TTES quality, supplied negating evidence. There seem to have been 21 cases, for twelve students, in which a TES first part score did not indicate a transformative experience, while the answer for the open ended question for the same student did indicate transformative experience. The opposite situation, in which an answer for an open question did not testify of a transformative experience while the statements score of the same quality indicated a transformative experience, happened in 10 cases for seven students. Table 8 presents representing answers for both cases. Table 9 presents representing answers of the regular pattern, in which there is compatibility between both parts of the TES. The TES statements mean average score is considered high above a score of 3.5, and low below 3.5. The TES open-question score is considered high above 1.5, and low below a 1.5 value.

Table 8 - TES statements average score for a TTES quality, and an answer to the TES opened question of the TTES quality for the same student exemplifying a contradictory nature.

Idle Student number	**TTES measured quality**	**TES statements mean average score** [1-6] (commentary)	**TES open-question score** [0-3] (commentary)	**TES open-question relevant answer**
3644	AU	2.89 (low)	2.8 (high)	*"I have seen the plants on my roof in a different way"*
3722	AU	4.11 (high)	0 (low)	*"I don't have an example"*
3650	EP	2.8 (low)	3 (high)	*"While photographing a leaf, I thought about evolution "*
3646	EP	4.8 (high)	0 (low)	*"I didn't like the course"*
3644	EV	2.33 (low)	3 (high)	*"The value of taking care of the environment"*
3793	EV	4.5 (high)	1 (low)	*"I think there are many values for learning new things, but again I do not feel that I have learned much in this program. It was very unfriendly to learn. You have much to improve "*

Table 8 demonstrates a pattern that is typical, when examining the data as a whole. When a high TES statements mean average score is accompanied by a low TES open-question score, the answers splits into one of two notions: either the student is unhappy with the unit itself, or that an example simply does not come to mind. Both answers, however informative, are irrelevant regarding the question’s subject. On the other hand, when a low TES statements mean average score is accompanied by a high TES open-question score, the answers offer a very specific example as requested, that has an obvious connection to the student's everyday life. It is evidence for the student's perceived transformative quality. This testimony stands in contradiction to the student's statements in the first part of the TES statements section.

Table 9 - TES statements average score for a TTES quality, and an answer to the TES opened question of the TTES quality for the same student exemplifying a compatible nature.

Idle Student number	**TTES measured quality**	**TES statements mean average score** [1-6] (commentary)	**TES open-question score** [0-3] (commentary)	**TES open-question relevant answer**
3794	AU	4.11 (high)	3 (high)	*"I have watched T.V with my family. We watched a show on special animals with unique habitats, and I checked out their adaptation to their environment out of my free will"*
3650	AU	3.22 (low)	1 (low)	*"I thought about it when I was doing classwork "*
3795	EP	3.60 (high)	3 (high)	*"I thought about the subject on my way home. After one of the lessons, I thought about man (kind), and what we used to be, and that it's insane that we have evolved this way"*
3652	EP	3.00 (low)	1 (low)	*"I don't have an example"*
3794	EV	3.67 (high)	2.8 (high)	*"I think it's very interesting to know what evolution is, and what causes it, and to mainly understand that it is something that happens in this very moment, and that the world is still changing and will change in the future, as well as us (humans) in compatibility with the environment"*
3642	EV	1.50 (low)	1 (low)	*"I do not find a value"*

Table 7 demonstrates a pattern that is typical, when examining the data as a whole. When a high TES statements mean average score is accompanied by a high TES open-question score, the answers are usually informative, elaborate, and offer a glance into the students' thoughts, when each answer is a testimony to its transformative quality and a live demonstration of it. On the other hand, when a low TES closed-questions mean average score is accompanied by a low TES open-question score, the answers represent a lack of example, or an experience limited to class work alone, thus does not testify to a transformation as expected.

Some observations arise from the comparison Table 8 and Table 9 present. The TES analysis results can be meaningfully divided into four response analysis types, that are relevant for all the TTES qualities. Table 10 depicts all four types and presents the TES open-question answers' characteristics.

Table 10 - TES four types of response analysis

TES response analysis type	**TES statements average score** (TES items 1..20)	**TES open-question score** (TES items 21..23)	**TES open-question characteristics of answers**
Type 1	high	high	***Length:*** Long (3-… sentences). A full answer. ***Content:*** Informative, elaborative, sharing thoughts, feelings and examples. ***Transformative experience:*** A fully expressed TTES quality indicative of transformation.
Type 2	high	low	***Length:*** Variable. ***Content:*** Expressing dissatisfaction from learning experience through the unit or "*can't find an example*". ***Transformative experience:*** Unknown. The answers are not relevant for transformation assessment. Dealing with aspects of the learning experience itself.
Type 3	low	high	***Length:*** Short (1-2 sentences). ***Content:*** thoughts and examples that express changed perspective. ***Transformative experience:*** A partially expressed TTES quality indicative of a transformative process.
Type 4	low	low	***Length:*** Extremely short (1 sentence). ***Content:*** Negatively phrased: "*don't know*", "*don't have*", "*can't find*", "*only for…*" ***Transformative experience:*** None. No indication of a transformative process.

When the TES answers (e.g. presented in Tables 8 & 9) are grouped and reviewed according to the four types of TES response analysis presented by Table 10, a transformative range is created. On one side of the range located response analysis type 4, presenting no transformative experience. On the other side of the range located response analysis type 1, presenting A fully expressed TTES quality indicative of transformation. The other two types are interesting and open for interpretation. Response analysis type 2 answers to the TES open questions are not relevant for transformation assessment. They refer to the unit's user interface, or the unit itself and not to the evolution ideas. Since the statements part of the TES testifies to a transformative experience, I could relate to type 2 results as an indication of a transformative process. Response analysis type 3 answers to the TES open questions are most interesting. Despite the fact that the statements part of the TES give no indication of a transformative experience, the TES open-question answers present thoughts and real life examples that express a changed perspective. That manifestation of a TTES quality could be indicative of a transformation in process.

When taking into account the complete TES results to estimate the unit's influence on its learners, the outcomes are pointing toward the unit's ability to invoke transformation with an emphasis on the EP and EV aspects of the transformative experiences. The TES statements' descriptive statistics show a positive inclination toward transformation, in the EP aspect of the transformative experience. The other aspects (AU & EV) results are not far behind with values above 3. Not pointing positively toward a transformation, but not adamantly pointing away from it. The number of students, in the answers to the TES open questions, reporting of an experience that is scored as expressing a transformative quality, is relatively high with 56%-82% depending on the quality. The TES opened questions average scores themselves are indicative of transformative experiences. So much indeed, that when they intersect with TES statements descriptive statistics results, it could be claimed that the overall effect is positively indicative to most students being in different stages of a transformative process. Examining the TES opened questions answer characteristics in conjunction with the TES complete scores led to the identification of TES response analysis types. When closely examining types 1-3, it becomes apparent that even students that were scored low on one of the TES parts, should be considered as being in a transformative process.

A previous attempt to characterize different levels and combinations of the transformative qualities described them as profiles of transformative engagement, with three distinctive student's profiles: a high, a medium and a low transformative engagement profile (Pugh, Bergstrom, & Spencer, 2017). That research used a coding scheme to evaluate the transformative engagement with different TTES qualities in interviews. A similar coding scheme was used in this research to evaluate the level of transformation expressed by the students regarding the different TTES qualities in the TES open questions responses. The difference is that in my analysis the TES open questions response analysis was combined with the TES closed statements scores to produced four types of response analysis. Based on the joined coding scheme, and the profiles description it can be claimed that the high and low transformative engagement profiles roughly correspond to this research TES response analysis type 1 and type 4, respectively, and the medium transformative engagement profile correspond to this research TES response analysis type 3. Since the transformative experience in type 2 TES response is unknown, it cannot be related to Pugh, Bergstrom, & Spencer's (2017) presented transformative engagement profiles. Despite that, the previous study strengthen the concept of a transformative range as expressing different levels of transformation, and the view of transformation as a process.

The overall picture supports the assertion that the learners of the online evolution teaching unit were influenced by the unit. They did report of transformative experiences: they found interest in learning the evolution ideas, that expressed in talking and thinking about these evolution ideas. They reported a new view of situations and experiences, and shared meaningful experiences and thoughts that expressed all the different qualities the TTES model intend to inspire. This assessment leads me to say that the results establish that a transformative experience can be inspired and driven by the TTES based online evolution teaching unit.

If and to what extent the learners of the online evolution teaching unit experience a conceptual change toward the scientifically acceptable model?

To address the second research question, I employed three measures: the Evolution Reasoning Scale (ERS), the Perception Board (PB) and a narrative analysis of the written unit's artifacts. Unfortunately, the quantitative measures turned out less than fit for the task, since the Cronbach Coefficient Alpha turned out to be of low value for both, the ERS taken in the unit's introduction, and in subunit five. This outcome prohibited relating any meaning to the averaging of the ERS results. The Perception Board results analysis did not reveal any joined pattern. Comparing the average results of each of the eight venues of the PB completion, was performed for the complete board results, and for each of the board different perceptions, yet did not present any statistically significant trend. These results have taken me by surprise since both measures were successfully used before. The ERS low reproducibility values led me to the hypothesis that the guidance which was given to the teachers regarding the use of these research tools was not sufficient. For example, the teachers were not instructed to motivate their students to take these questions seriously, and to try and answer according to their learned knowledge. Another hypothesis refers to the Perception Board results. In previous research (see appendix E) the Perception Board was an actual physical board that retained the last entries of every student by name. Since there was one board for all the students, there could have been an element of social learning that might have an influence in creating joined patterns. Another possibility relates to the fact that the physical board was hanging in the class while the instruction took place, which might have allowed for students to continually assess themselves in reference to the board's perceptions as learning progressed. However, in the unit there were eight different digital instances of the Perception Board, one at the unit's beginning and the others at the end of every subunit. It is possible that since the students did not have their previous board entries before them, and since the filling of the board was independent and blind to the other students stands, and was not visible all through the learning process, the results did not show any joined patterns, and reflected only the personal trajectory of perception evolvement.

The narrative analysis of the unit's artifacts for conceptual change and for holding the scientific view of evolution was performed for every student who learned the unit and produced texts. The analysis yielded results: 11 students, out of 31 (35%) were found by narrative analysis to have gone through a conceptual change process, and 16 students, out of 31 (50%) were found by narrative analysis to reach the scientific view of evolution. However, the extent to which the different students learned the unit differed. Table 11 presents the segmentation of students unit's completion rates.

Table 11 - The students unit's completion rates

Completion rates	**Number of students**
90%-100%	12
80% - 89%	5
70%-79%	5
0% - 69%	9
n Total	31

The completion rates mean difference between students who were found by the narrative analysis to hold the scientific view of evolution, and students who were not found to hold the scientific view of evolution, was tested by the parametric T-Test and by the nonparametric Kruskal-Wallis Test. The results are presented in Table 12.

Table 12 - The T-Test and Kruskal-Wallis Test results of completion rates mean difference between students holding the scientific view of evolution, and students who were not.

T-Test		
t-value	DF (freedom degrees)	p-value
3.32	24	0.003
Kruskal-Wallis Test		
Chi-Square	DF (freedom degrees)	p-value
8.8	1	0.003

Both tests deemed the completion rates mean difference between students who were found by the narrative analysis to hold the scientific view of evolution, and students who were not found to hold the scientific view of evolution significant, meriting a deeper examination.

We explored the unit's completion rates in connection to the rate of students that were found by narrative analysis to have gone through a conceptual change process, and to students who the narrative analysis found to hold the scientific view of evolution. It is important to notice that the group of students who were found by narrative analysis to have gone through a conceptual change process, is included within the group of students who the narrative analysis found to hold the scientific view of evolution. Three students continuously exhibited perceptions that were in line with the scientific model of evolution all through the unit. These students did not exhibit conceptual change, but rather maintained and deepened their scientific view.

Reviewing the narrative analysis of the student's artifacts revealed three cases in which there were repeated researcher remarks regarding the students unit's answer texts being identical to the answer texts of several other different students. In two of the cases the students (idle ID 3650, and 3652) had a completion rate higher than 90%, and in the third case the one student (idle ID 3655) had a completion rate higher than 80%. The ambiguous nature of the origin of these students texts raised a question as to how much these student's artifacts may testify to these students' learning process. We chose to remove these three students results from the results pull, in order to receive a picture that accurately testifies to the unit's influence, thus n=28. Figure 1 presents the percentage of students holding the scientific view of evolution and experiencing conceptual change as dependent on their unit's completion rate, for the revised sample.

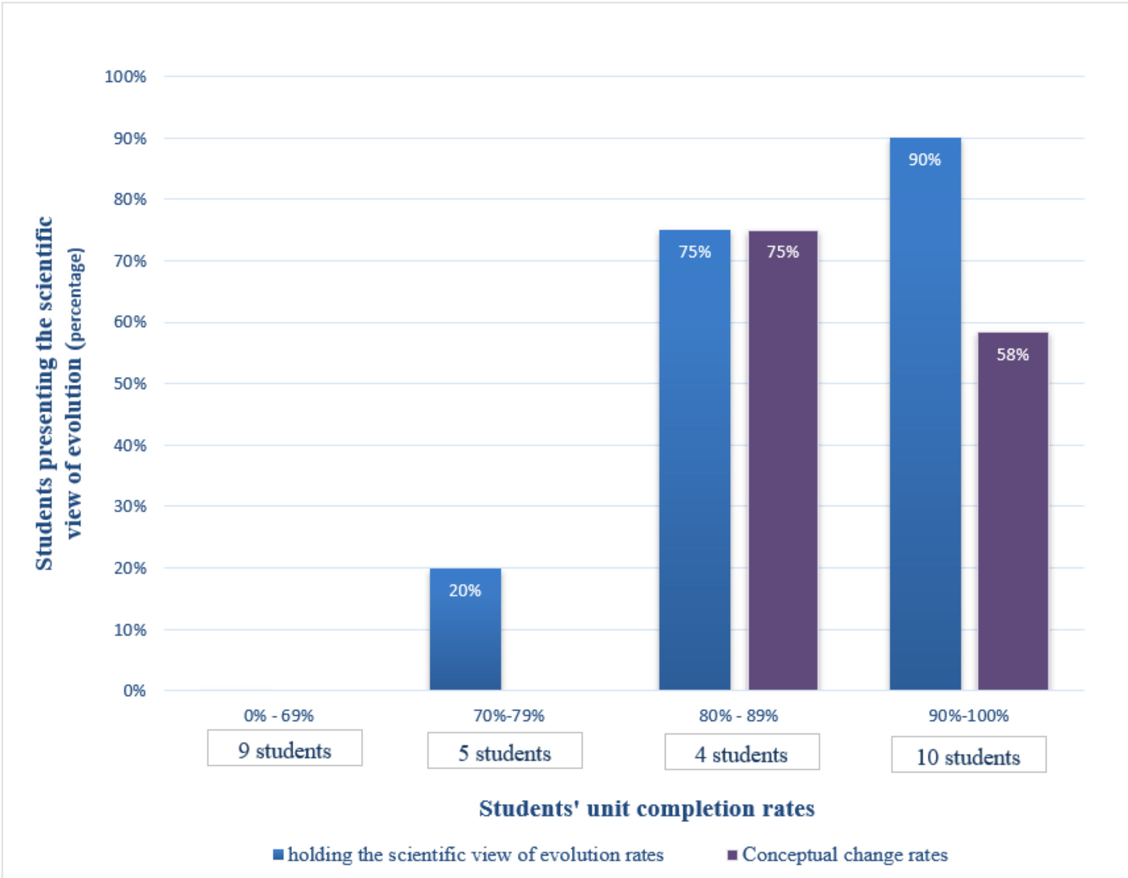

Figure 1 The percentage of students holding the scientific view of evolution and experiencing conceptual change dependent on their unit's completion rate (n=28)

This exploration revealed that conceptual change toward the scientific view of evolution has been found only with students who completed 80% or more of the unit's learning tasks. High completion rates also seem to correlate with students that reached the scientific view of evolution. Figure 1 presents a picture in which, students who's learning completion percentage is lower than 69% did not exhibit a scientific view of evolution. Only 20% of the students who's learning completion percentage was in the 70% - 79% range achieved the scientific view of evolution. This achievement rises to 75% and even 90% of students exhibiting the scientific view of evolution when learning completion percentage is in the range of 80% - 89%, and 90% - 100% respectively. This pattern suggests that above 70% unit's completion, the higher the student's completion percentage is, the higher her/his possibilities for achieving the scientific view of evolution when learning through the unit are.

The narrative analysis presented evidence of conceptual change toward the scientific view of evolution among learners of the online evolution teaching unit, and evidence of unit's learners who reached the scientific view of evolution. A further analysis revealed the extent of the change. High levels of the scientific view of evolution as well as high levels of conceptual change toward the scientific view of evolution were presented only for students who's unit's completion rates were high, attesting to the unit's influence.

What are the characteristics of the learners' conceptual change process while learning using the online evolution teaching unit progresses?

To address the third research question, I chose to apply two approaches. The first is to explore the learning process of two particular students that show similar unit completion rates, but differ in their conceptual evolvement results. One achieved the scientific accepted view of evolution according to the narrative analysis, and the other did not. The second approach is rather general, and characterizes the students' conceptual evolvement process as a whole, pointing to patterns that emerge from an inductive review of the students' artifacts produced along the learning process of the unit.

Student A & student B

The two students that were chosen for this analysis are student idle ID 3791, and student idle ID 3657, whom I will refer to from now on as student A and student B, respectively, for the sake of easier reference. Student A had a unit completion rate of 94%, and was found by narrative analysis to have gone through a conceptual change process, and achieved a scientific accepted view of evolution. Whereas student B, who had a unit completion rate of 91%, was found by narrative analysis to hold a view of evolution that is not in line with the scientific one, and not to have gone through a conceptual change process. The Perception Board visual representation which was prepared for students A and B, is presented in Figure 2 and Figure 3, respectively.

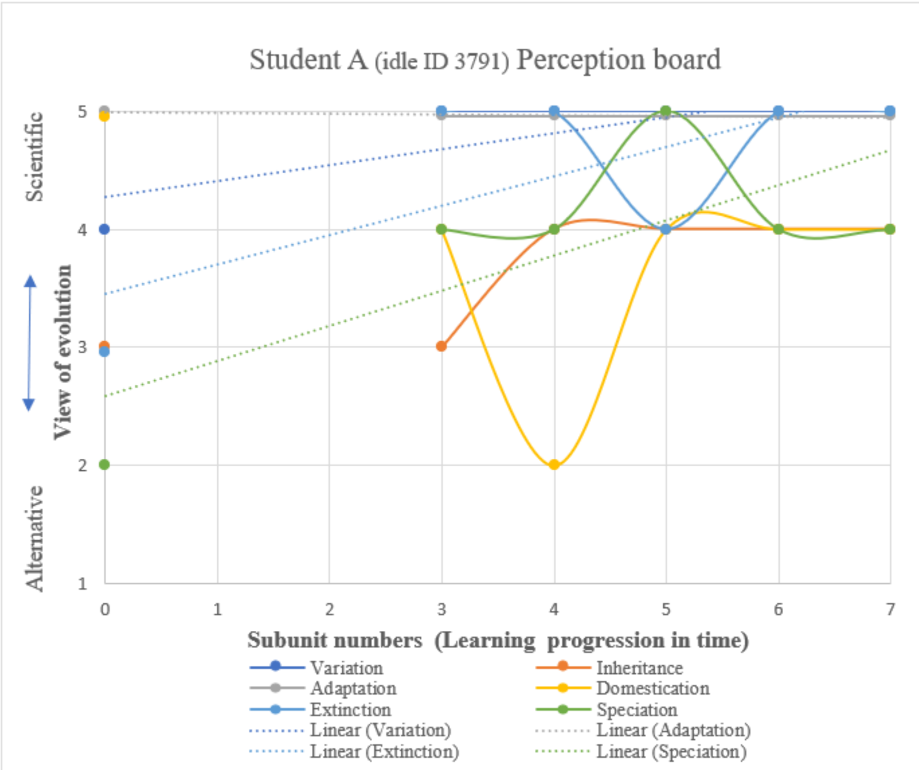

Figure 2 The Perception Board representation of Student A. Perception Board data entry for subunit 1 and 2 was not registered. The linear present the individual concept's evolvement trend. A perception is considered as to express a conceptual change, when its pattern moved from the alternative view (1-2) to the scientific view (4-5) of the concept.

When inspecting student A's last Perception Board's entries, which represent the end of the unit's learning process, it is clear that student A holds a strong perception of hers/his scientific view regarding the concepts of adaptation, variation and extinction. Adaptation and variation that are two major subjects the unit address, whereas extinction and speciation are addressed by the unit as minor subjects. This scientific view is represented by the student's confident choice (that was scored 5) of the scientifically acceptable (i.e. variational) interpretation for these concepts (as presented by Table 2). Student A holds the scientific view regarding the concept of speciation as well, but with less conviction (the perception was scored 4). Other subjects that were not directly attended by the unit (inheritance & domestication), were scored relatively high as well, yet presented a different perception evolvement process. In contrast to the learned concepts of adaptation, variation, extinction and speciation, which reached the range of the scientific view of evolution (i.e. were scored 4-5) early on (by subunit 3) and oscillated within this range, the concepts of inheritance and domestication oscillated around the midpoint (i.e. were scored 3) or in the range of the alternative view of evolution (i.e. were scored 1-2), and stabilized later on (by unit 5) on a fairly confident scientific view.

When examining the perception evolvement process of the learned concepts more closely, the trendlines presents the preservation of the scientific view regarding the concept of adaptation, an ascending trend toward the scientific view regarding variation and extinction, and a strong ascending trend from an alternative perception toward a scientific perception regarding speciation signifying conceptual change in the perception of this concept. Unfortunately I do not have perceptions entries for student A during subunits 1 and 2, yet it is evident that by the end of subunit 3, student A already possesses a new and somewhat confident scientific view of speciation. That means that the evolvement in student A's views, which we may refer to as conceptual change was bound to occur prior to subunit 3's end. The confidence of student A in the scientific view of speciation rises by the end of subunit 5, that deals directly with speciation, but in a turn of events regresses by the end of subunit 6, that deals with human evolution. Student A holds a fairly confident scientific view until the unit's end.

The perception board entries are a self-made testimony of students perceptions. Combined with the narrative analysis of the students' artifacts, they offer a wider picture attesting to the students perception evolvement. When examining student A's narrative analysis we get the "behind the scenes" information. This data may be used to fill in the gaps in knowledge, explain the pattern the Perception Board exhibits and shed light on student A's conceptual change characteristics of the learned concepts.

In subunit 1, who's subject is observing nature, student A recognizes the organisms attributes and a match between organism's structure and function is expressed: "*The Cinnyris osea has a long rounded beak that is suitable for eating nectar…*". It is noticeable that at this stage student A relates to the *Cinnyris osea* attributes as serving a private purpose for the organism: "*The Cinnyris osea flies well,* ***because*** *while she eats the nectar from the flower, she has to keep balancing herself.* "; or "*The pollen of the Lilium candidum hang outside the flower* ***in order to*** *attract insects*". These perceptions suite the recognized connection displayed in the preliminary Perception Board entry of the concept of adaptation between organism qualities and the environment. In subunit 2 that deals with organism's adaptation, student

A’s repeatedly mentions camouflage and survival as desirable outcomes of adaptation for the individual organism: “*The turtle is brown, and it disguises itself in the ground, so it is hidden from predators. The turtle has hard armor, similar to stone, so it is both hidden and protected from predators who will try to eat it*”. An elaborated observation was submitted in subunit 2 (All of student A’s submissions are presented together with student B’s submissions in appendix D).

Subunit 3, which presents the concept of natural selection, seems to spark a profound understanding as to the nature of evolution, and to initiate a different view. This changed view is expressed in the Perception Board entry of subunit 3 for the concept of speciation. Subunit 3 opens with a request to read about the terms evolution, adaptation, fitness, variation, and natural selection, and to offer a personal definition: “*Use your own words*”. Student A’s definitions reveal a perception of organism transformation, in which traits are a part of an organism’s essence and change according to the organism’s need: “*Adaptation – are attributes that allow the organism to adjust itself to the environment*”, or “*Natural selection – is an outcome of an organism’s coping with the environment, that an organism is developing according to its environment. That’s what is helping him to survive* ”. The subunit continues with an experiment using different kinds of objects as “beaks” (a teaspoon, chopsticks, a straw, etc.), and evaluate their ability to get “bird food” (lentils, legumes, small noodles, rice, etc.). One of the questions in that activity refers to what would happen if the surrounding became watery. The students are asked to describe the experiment, and it’s purpose, and to submit a report. Student A answered correctly and submitted a thorough report (see appendix D). The point that tilted student A’s perception followed: the students were invited to watch a short video media about Darwin’s finches and/or to read about them in a text. They were then asked to explain how the drought influenced the shape of the finches beaks, and to state the connection between the drought to the short time of the shape change of the finches beaks. During the activity, student A developed an understanding of the natural selection process, the connection to reproduction, and its effect on the rate of development, as apparent by the answer: “*The connection is that during the drought, plant-eating finches had no food and therefore they soon became extinct, because of natural selection, but the finches who ate insects had the ability to survive and they were the ones who brought offspring and continued to exist. The time it took was shorter because from the moment* *the drought began, it didn't take long for the rest of the species to become extinct from lack of food*". Here we see a perception of the mechanism of evolution. A realization as to the nature of an adaptive quality and its relation to fitness. It's a complete opposite of the perception presented at the beginning of the subunit, that leads me to believe that this is the perceptual tipping point that played a major role in student A's conceptual change, that is manifested by the Perception board. Student A recognizes the influence of the subunits learning activities on the perception: "*The activity helped me to better understand natural selection, and the whole process of species evolvement and how every individual came from the process of natural selection. Whether it's drought or temperature conditions, everything in nature has a reason.*". Student A seems to trade the perception that the cause for a feature existence is its private benefit for the organism, with the perception that the cause of the feature is external to the organism and is rooted in the environmental conditions (such as drought). Actually, this perception is so strong with student A, that in end of subunit 4, in an answer to the question: "*does every feature necessarily attest to adaptation?*", student A responds:" *I think every preserved trait is a sign of an adaptation to the environment. Some features may no longer be in use after many years, but originally each feature was created from adaptation to the environment*". Student A's excellent understanding of the evolution process manifests in the creative comics style story that was submitted in subunit 4, that followed the virtual moth lab simulation, and presented the moths' story, as it took place in reality. This process resembles the one in subunit 3 in which the actual finches story followed the "beaks" activity.

The variation lab that took place in subunit 5, accompanied by learning about the speciation of salamanders moves student A to perceive variation as fodder to the natural selection process, and to proclaim that an evolution advantage does not exist in every environment. This subunit's learned topics coincide with an increase demonstrated by the Perception Board entry of subunit 5 for the concept of speciation. In subunit 6, that practices the students in all the subunits content, with a human evolution example, there is an interesting occurrence. Despite the strong scientific view of evolution demonstrated by student A, there is a slight conceptual change in the direction of an alternative conception, as evident by the statement: "*My answer hasn't changed, only that people won't be born darker to begin with, they'll just sunbathe and slowly it'll become something in the genotype as well*". This answer attributes the environment the power to influence an individual traits directly, and to change them, thus suggesting that student A's perception is transformational rather than variational. However, other answers of student A in this subunit, that list "*Natural variability caused by things such as mutations, the passage of meiosis genes and epigenetics*" as genetic influencing factors, and "*changes in weather, global warming, and prolonged exposure to radiation*" as environmental factors, as well as the position paper that was submitted in this subunit (see appendix D), moderate this assumption. This momentarily shift in perception coincides with the decline that the Perception Board entry of subunit 6 for the concept of speciation exhibits.

Only a few questions during the unit's learning process are meant to bring the students to reflect on their worldview expansion. Student A's answer to this kind of question in subunit 7 completes the picture regarding the evolution learning process: "*The unit was interesting, it mostly made me think more deeply and not just accept things as they are without trying to understand them. At first I had all sorts of difficulties understanding, especially on a board of perceptions, but as I continued in the unit and progressed, I felt that I understood more and more... ... I think I can see nature a little differently, and also see how human beings disrupted the real process of evolution. I can now see that evolution is really mostly a fit for the environment, and not always "the strong survives". I feel like I've been able to understand part of nature's secret, but I still have a lot to learn to really understand how things got to the way they are today*". It seems that student A speaks in the transformative metaphor language of the unit, and binds the expansion in perception (that of course encapsulates the conceptual evolvement and change) to the transformative practices of the unit ("*made me think more deeply*". "*I can **see** nature a little differently*").

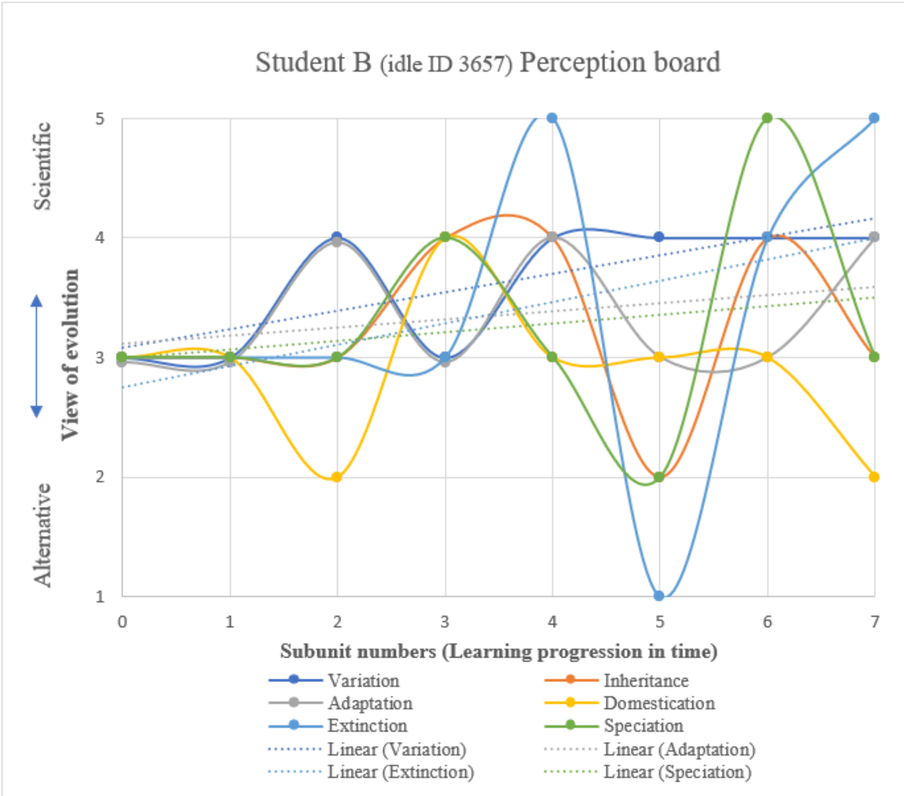

Figure 3 The Perception Board representation of Student B. The linear presents the individual concept's evolvement trend. A perception is considered as to express a conceptual change, when its pattern moved from the alternative view (1-2) to a scientific view (4-5) of the concept.

Student B's Perception Board representation for all the examined concepts show a strong oscillating pattern, which in the case of the concepts of variation and adaptation oscillates within the range of the scientific view of evolution. The concept of variation stabilizes with in the scientific view range by subunit 4, yet the concept of adaptation does not stabilize and keep oscillating between an undefined view (i.e. were scored 3) and a mildly confident scientific view (i.e. were scored 4). In contrast, when regarding the representation of the perception evolvement process of the speciation, extinction, inheritance and domestication concepts, it portrays a picture of a perceptions that alternate between the scientific view of evolution and an alternative view. When inspecting the last subunits, which represent the end of the unit's learning process, it seems that student B holds a strong perception of hers/his scientific view regarding the concept of extinction (that were scored 5), a fairly confident scientific view regarding the concepts of adaptation and variation (that were scored 4), yet holds an undistinctive view regarding the concept of speciation and inheritance by the end of subunit 7 (the perception was scored 3). This closing view finalizes a process involving conceptual changes (demonstrated by subunit 5's entry that is scored 2 as an alternative view), but not resulting in a conceptual change. By the end of subunit 7 student B also holds a perception of hers/his alternative perception regarding the concept of domestication. For the perception evolvement process itself, the trendlines present a slight increase in confidence, and the preservation of the scientific view regarding the concept of adaptation and variation, and a tendency toward a scientific perception regarding speciation during learning, that did not fall through. It is interesting to compare the perception board's analysis, with the narrative analysis of student B's artifacts. Since the perception board entries are a self-made, it is interesting that student B Perception Board entries attest to a view of evolution that has a tendency toward the scientific view of evolution, which the narrative analysis does not endorse.

In subunit 1, whos' subject is observing nature, student B does not notice specific features. Student B addresses the organism as a whole: "*A pretty bird, gleaming with color… …small bird. elegant*". Student B connects the *Cinnyris osea* attributes to an assumption of function, that is seemed to be based on general knowledge rather than observation: "*The bird probably knows how to fly. It drinks nectar, because it has a long beak, and that's why they call her a Cinnyris osea*". Later on, student B does not relate the flowers structure to the way they are pollinated. The lack of reference to any evolution related concept seems to be suited to the non-distinctive score displayed in the preliminary Perception Board entry for all concepts. In subunit 2, that deals with organisms adaptation, student B mentions several features of organisms in relation to survival, and while doing so reveals a perception of organism transformation: "*The frog is green and adjusts its color to the green nature, that allows it better acclimation and survival*". Student B's answers in this subunit are elaborated, and show a good recognition of the adaptations type in the subunit exercises. This could correlate with the elevation in the Perception Board entry for the concepts of adaptation and variation to a scientific point of view. It should be noted that the observation exercise for subunit 2 was not submitted by student B.

Subunit 3, which presents the concept of natural selection, was done off-hand. When reading student B's answers, to subunit 3's request for reading about certain concepts (evolution, adaptation, fitness, variation, and natural selection) and to offering a personal definition, it was clear that one of two scenarios took place, either no such reading was done, or the reading did not result in comprehension of the text. Some examples: "*Fitness is when something is fit. For example a soldier is fit to its post*", or "*Natural selection – is the decision of nature to choose something, and this will be its natural selection* ". The subunit continues with the previously mentioned "beaks" experiment, after which the students are asked to describe the experiment, and it's purpose, and to submit a report. Student B answered correctly, but submitted a handwritten photographed report (see appendix D), that included only a results table, lacking a conclusion. Student B neither performed the exercise about Darwin's finches, nor explained the connection between the drought and the finches beak's shape. Perhaps his the off-hand relation to this subunit is reflected in the reduction of the Perception Board entries for the concepts of adaptation and variation, and perhaps the "beaks" activity has something to do with the elevation of the Perception Board entry for the concept of speciation – but the narrative analysis does not point to any evidence to support this hypotheses. Subunit 4 subject was industrial melanism. In this unit student B submitted full elaborated answers, and a virtual moth lab report (see appendix D), but did not submit a creative assignment of the real moths story. Students B lab reports tell an interesting story. The virtual lab simulates a light and dark tree bark riddled with light and dark moths. The student, who assumes the role of the bird, is timed when hunting for moths. The software compiles the light and dark caught moths statistics, and displays it to the student for conclusion. Students B's virtual lab reports show 50% dark caught moths and 50% light caught moths at any given environment – light bark or dark (see appendix D). Since it is easier to spot moths in a contrast shade to the bark, achieving such a result demands a real effort to beat the system. This kind of effort suggests intent. The intent is unknown, but exists. The rest of the unit reveals a perception of organism transformation, and lacks the perception of traits consistency (the idea that features do not change during the organism's lifetime): "*The moths were light at the beginning, and so were the trees, so the moths could blend in the background, and when the tree darkened, so did the moths*". It also seems that student B holds to a perception that a DNA mutation can influence an organism phenotype during his lifetime: "*a mutation is a biological term, so it describes a change in the sequence of DNA. It can happen spontaneously, and even externally - the mutation* *caused the appearance of black spots for certain moths*". In the same subunit, student B conveys a contradictory perception, that characterizes the evolution process as long, but given to the organisms choice, and profits the individual organism: "*The bear is asleep during the winter period because it is very cold and difficult to go out and look for food. As a result it is difficult to exist, so in a long evolutionary process the bears have reached the point where they sleep all winter, so they will not suffer and could survive later on*". This perception seem to replace adaptation with adjustment. Yet again none of the written evidence supports the changes the Perception board reflects.

The variation lab took place in subunit 5, accompanied by learning about the speciation of salamanders. Student B recognizes the difference between organisms of the same species, but does not perceive the role of variation in the evolution process. The Perception Board entry of subunit 5 for the concept of speciation shows a steep decline in speciation and a decline of adaptation, again with no specific related evidence. It is important to note that student B's answers in this subunit are very short, and usually end after one sentence. Subunit 6, that practices the students in all the subunits content, with a human evolution example, seals the received impression so far by exemplifying perceptions of organism's transformation within its lifetime , that is hereditary. These messages are presented as is, with no mechanistic explanation to them: "*The genetic factors are the parents of the baby, so if they are dark skinned, the child's skin will be darker. … the sun will strengthen it in time… the baby will become darker, and in the future, the baby's child will also be darker*". Student B did not submit subunit 6's position paper.

Students B's answer to subunit 7's question completes the picture regarding the evolution learning process: "*It was a lot of fun and I learned a lot*".

When following the different routes the learning process of student A and student B through the unit takes, to very different outcomes, different and joined characteristics of their learning processes appear:

Investment in the learning process.

Despite their similar unit’s completion rate, the difference in the learning investment between student A and student B, all through the unit is considerable. This difference manifests itself in two distinct parameters:

Independent preparation – this parameter signifies the independent work the student is being asked to do, as preceding work to an exercise or as an articulation of the learned ideas. Examples to such independent work one may find in applying the observation and adaptation which was learned in subunits 1 & 2, to an observation exercise done at home that student A submitted, and student B did not, or online reading about the meaning of several concepts (adaptation, fitness, etc.) before offering personal definitions in subunit 3, which was done by student A, and which student B probably did not perform, or performed in a manner that was not conducive to the assignment, which was lacking a knowledge base.

Work depth and elaboration – sharing thoughts and examples, whether done as a reply to an exercise question or in a submitted assignment, testifies to taking the time to come up with them. student A invested thought and time in sharing views creatively. It is evident from the lengthy elaborate answers, that is laced with examples, to every question as much as from the creative work of student A’a summation of the industrial melanism process in subunit 4. Student B invested thought and effort in some subunits, as seen in the elaborate examples of subunit 2 & 4, however, in the rest of the subunits, student’ B answers were limited, and work products exemplifying thoughts and effort such as a creative product to explain the evolution process (subunit 4) or a position paper on skin color discrimination (subunit 6), were not submitted. It should be noted that the completion rate is not much different between the two students, but there is a big difference in the missing assignments. Student A skipped several repeating questions within the exercises, while student B skipped major exercises that demand much time, thought and effort.

Perceptual "tipping points"

Student A's reflective thoughts during the learning process provide a glimpse to the transformation process that nurses this conceptual change.

Two distinctive points in student A's conceptual evolvement process draw special attention. The first is in subunit 3. Prior to this subunit, student A sees an organism attributes as part of the organism's essence, that are perceived to change according to need. In subunit 3, student A completes a hands-on activity that simulates the possible connection between the shape of a "beak" and the types of "food" it can get. One of the questions in that activity refers to what would happen if the surrounding became watery. This activity is followed by the real-life story of Darwin finches. That is followed by a question regarding the influence of the drought. It seems that this particular combination of activities – hands-on artificial activity followed by an actual story that portrays the same learned ideas – coupled with questions of the same nature (of the influence of the environment changing conditions – watery environment / drought) led to the understanding of the concept of natural selection. Moreover, it pushed toward a population point of view (vs. the individual point of view student A exhibited in the unit's beginning), and constituted a perceptual tipping point that led to a conceptual change. The second distinctive point that draws attention in student A's conceptual evolvement process is in subunit 4. Student A completes a virtual moths lab activity that simulates the way the environment influences the moths population by selection. This activity is followed by the real-life story of the industrial melanism, which student A chose to express in the form of a creative comics style story. This combination of activities supported student A in her/his new view of adaptation as created by the environment, and reinforces student A's expanded perception that these changes happen in the population level. These two distinctive points influenced student A's perceptions regarding the concepts of adaptation and natural selection, and contributed to seeing adaptation as a process of trait selection at the population level, rather than a transformation of the individual organism's essence.

Interestingly, student B did not choose to perform these exact assignments. The reasons for that choice are unknown to us. The influence of that choice on student B's conceptual evolvement process is also unknown. However, a reasonable hypothesis, based on the significance of these points for the induction of the conceptual change of student A, would be that not engaging with the learning process the unit offers in these specific junctions impairs student B's (and possibly other students who did not choose to take part in learning the same points) conceptual evolvement toward the scientific view of evolution.

Scientific perception withdrawal in the human evolution subunit

It is clear from the narrative analysis, that both students, though following different learning trajectories and learning outcomes, refrain from mentioning or referring to death, extinction or fitness in the context of human's evolution. Subunit 6 presents an opportunity to link an environmental cue (sun radiation) to a hereditary trait (skin color) through a mechanistic explanation of evolution (radiation influence & the effects of sun deficiency). Both students exhibited a tendency to initiate an alternative explanation that does not involve fitness, or possible natural selection.

Inductive review of learning patterns & of the conceptual change process

In order to learn even more from the characteristics of the learning processes and the conceptual change, while learning through the unit, I present general insights that characterize the conceptual evolvement process of all students, pointing to patterns that emerge from an inductive review of the student's artifacts, that were produced along the learning process through the unit:

Conceptual evolvement and conceptual change routes are different among learners. Each learner interacts with the unit's ideas a little differently: the answers and examples are different, the learning pace is different, the unit's completion rates are different, the investment in the specific exercises and assignments is different among learners, and sometimes differ for the same learner. Changes in perception of ideas seem to happen gradually in the unit. This is sometimes expressed by intermediate states, in which different perceptions that expresses the opposite perceptions coincide, and in time one strengthens on account of the other.

For example, the next answer was written as part of subunit 3's "does your beak make you freak" activity. On the one hand there is a reference to the change that occurs over time (not immediately) and to population variance:

"*The purpose of the experiment in my opinion was to test the efficiency of each beak in obtaining food and thus to examine the effect of the different beak's forms that changed during evolution and to notice the variance of each beak*".

On the other hand, in the same activity there is a perception of a change that occurs quickly in the organism itself due to environmental pressure:

" *The connection between the drought and the short time it took to change the shape of the beaks is that the birds had to change their bodies in order to adapt to the environment, and not to become extinct from existence*"

It is difficult to understand what the student's worldview is, since the opinions appear in the jumble. Later on the perception of organism's transformation subsides and a perception of traits permanence appear: "*The white moths could not hide themselves from predators and therefore were devoured more than the black moths*".

In fewer times these changes are not clearly expressed in the evidence, and then the conceptual change seems to happen instantaneous. Either way, the moment the perception of the scientific view of evolution seem to clearly appear differ among learners. For some, much like student A, it is expressed in subunit 3, other in subunit 4 or subunit 5.

Trait permanence is a fundamental issue in understanding evolutionary change as happening in the population level, rather than an individual transformation. When a perception of trait permanence appeared in a text of a student that formerly presented a transformative view of evolution (meaning organism's traits change), it seemed to be a marker of conceptual change toward a scientific (variational) view of evolution.

For example, a student that perceived organism transformation as motivated by the organism internal need of survival: "*What made the organism develop (the trait) is the need to hunt and live*", after completing subunit 5, which deals with variation, refers to unchanged traits that deprive the organism out of his evolution advantage: "*a polar bear's white fur disguise him in a snowy environment. If the polar bear will find himself in an area that lacks snow, his trait will lose its effectivity*".

Language is very important. Speaking in plural might refer to the organisms themselves as individual ***or*** to the population. When students say: *"the moths have blackened"*, they do not necessarily mean to talk about a change in the organism. Sometimes there is an understanding that the moths' population has become blacker. It is spoken language, that differs from the scientific language. The sentences that accompany this statement might hint to the student's intention. For example, a students that writes: "*the color of the moths changed, factories influenced the color of the moths*" refers in following sentences to the mechanism in a population level: "*following man's inventions and environmental influences moths die, thus their population changes*". Yet, another student who proclaimed: "*the moths turn from white to black*", referred in following sentences to the mechanism of organism transformation, ***despite*** using the word population: "*the moth population decided to change their own color from white to black*".

Influence of mutations. The perception that some students express, that a mutation can effect an organism by actively changing the organism phenotype during that organism's lifetime , hinders the connection of the molecular level to the process of evolution: "*A mutation in the DNA caused the moths to become from white to black*". Another student expressed it differently: "*It happened spontaneously. The mutation caused black spots to appear*".

Determinism. It is prudent to notice that even when the evolution mechanism is understood by the students, perceptions of determinism may still take part and lead the students to believe that a species changes because it wants to or needs to for its survival: "*…something caused the elevation of the chameleon predators and that caused the chameleon to* *upgrade the defense systems*", or because it was driven by an external influence with intention: "*Nature preserved the black color of the moths to help them (the moths) adapt to the new situation, and survive*".

Human evolution is an issue*.** With all the students, even those who achieved an excellent understanding of the evolution process while learning the unit, there seem to have been a major difficulty engaging with the concept of human natural selection as part of human evolution. The words extinction, death or fitness were seldom written in that context, and other explanations appear. Even a student that used the word "die" in relation to the evolution mechanism for other organisms: "*The drought caused small seeded plants to be less common, and one kind of finches, that was with a small beak and could not crack large nuts* ***died *in big numbers due to lack of food*", completely ignored the evolution mechanism, and its consequences for humans: "*because of global warming skin color will get darker, and make the planet more global. People with different skin color will get together*". It seems to be a deliberate omission, with no evidence suggesting of the cause. This example offers an explanation that seem to have no connection to evolution at all, and represents just one kind of an alternative explanation. The students offer different alternative explanations for the evolution mechanism in the case of humans. Some explanation seem to "go back" perceptually to a nonscientific view that includes a direct environmental influence on an individual organism's traits (a transformational view): "*At first all humans were dark colored and created a lot of melanin. If they traveled to new places they had to adjust to the new environment they lived in*". Other explanations went around the subject: "*Because of global warming more UV will get to earth and hurt the skin. People who have dark colored skin will adapt quickly to this situation, because their skin produces more melanin to begin with, but people with bright color will suffer more burns and genetic mutations and in this evolutionary process people will start manufacturing much more melanin, and their body will get darker and darker as global warming progresses*". This answer clearly expresses some scientific concepts, such as variation (that recognizes different phenotypes to the trait), and trait's permanence ("*their skin produces more melanin to begin with*"), and even mutations, but instead of reminding offspring, fitness or selection the answer "goes around the subject", and without articulating how it will happen, insinuate to a process that will happen through the generations (“*their (/humans) body will get darker and darker*”). Some students even relinquish the perception of environmental influence altogether: “*Genetic elements are the only ones that can change skin color for human beings, and they will effect skin color in the future. The environment have no way of doing that*”.

DISCUSSION

In this thesis, my objective was to explore the possible transformative influence of an online evolution teaching unit, based on the TTES model qualities (EV, EP & AU), which was developed and used for teaching evolution to high school biology majors, on their conceptions of biological evolution. The results portrayed the transformative influence as a range, and confirmed that most of the unit's learners proceeded to different stages of a transformative process, with the TTES qualities of EP and EV leading the transformation. The resulting conceptual change toward the scientific view of evolution was detected only for learners who completed 80% or more of the unit's learning tasks. The student's conceptual evolvement process was characterized with findings regarding learning evolution through the unit (e.g. the identification of junctions in the unit's design, which constitute perception "tipping points" for conceptual change), and understanding evolution (e.g. the deliberate omission of the concepts (and words) extinction, death or fitness in the context of human evolution). The results are discussed in relation to the research questions. Following the research conclusions, the research limitations will be presented before delving into possible implications relevant for education researchers, teachers and learning materials designers, as into thoughts of future research directions.

The transformative experiences reported by the unit's learners

The transformative experiences reported by the unit's learners attest to the transformative influence of the unit. Past results, such as conceptual change and understanding (Girod et al., 2010; Heddy & Sinatra, 2013; Pugh, Bergstrom, & Spencer, 2017; Pugh et al., 2010), increased interest and efficacy (Girod et al., 2003; Girod et al., 2010), high levels of engagement (Heddy & Sinatra, 2013; Pugh, Bergstrom, Heddy, et al., 2017), and increased levels of enjoyment (Heddy & Sinatra, 2013), associated with the implementation of the TTES model could not be automatically expected in the current research, since both the implementation medium (i.e. using a digital instrument as a vehicle for inducing transformation), and the TTES model design adaptation for this digital medium, are completely new. Thus, evidence of a transformative process, may be a proof of concept for the feasibility of using the evolution teaching unit as an implementation medium, and its design as adequate for the induction of the TTES model's qualities, and merit an elaborate design research.

The first research question: "*If and what transformative experiences will be reported by the learners of the online evolution teaching unit?*" is answered affirmatively by the results that point toward the unit's ability to invoke transformation with an emphasis on the EP and EV aspects of the transformative experiences. The hypothesis of "*learning evolution using the unit would initiate a transformation process, manifesting in a transformative experiences*" is validated, especially considering the presented transformative range, that encapsulated learners in different stages of the transformative process.

In line with prior research demonstrating the TTES model's ability to induce transformative experiences in class (Alongi, 2014; Girod et al., 2003; Girod et al., 2010; Heddy & Sinatra, 2013; Pugh, 2004; Pugh et al., 2010), the transformative range, which presents different stages in the student's transformative process, attests to the online evolution teaching unit's ability to induce transformative experiences. Since there is no body of knowledge regarding the possible transformative influence of online learning, these preliminary findings strengthen the feasibility of using the online evolution teaching unit as an acceptable TTES based implementation medium.

The transformative range also draws attention to the differences in the transformative influence of the unit. The presented differences between the transformative range's four types (Table 10) contribute to the perception of transformation as a continuum. A similar range was reported by a research implementing the TTES model in class (i.e. using a different implementation medium) as part of an effort to characterize different levels and combinations of the transformative qualities and to describe them as profiles of transformative engagement. This research identified engagement profiles ranging from minimally transformative learning to highly transformative learning (Pugh, Bergstrom, & Spencer, 2017). Taking into account that another study, which characterizes the degree of the learner's transformative experience following instruction through the TTES model, though using a different implementation medium, present the transformative experience of the learners as a range, strengthens my perception that regards transformation as a continuum.

The TTES model's ability to induce transformation is dependent on the model's ability to induce each of its three qualities (AU,EP & EV) (Pugh & Girod, 2007). The results, exhibit different levels of transformative experiences for each quality, when AU receives the lowest scores of all the three qualities. In my previous study implementing the TTES model in class (See Appendix E), a high level of AU (demonstrated AU rather than self-reported AU) was presented. This difference between the results of the two studies needs to be addressed. The main difference in the implementation of the two studies from the behavioral aspect is that the class lessons offered many opportunities for students to share AU experiences, and these opportunities were used, while in the online evolution teaching unit this aspect was expressed by sharing AU experiences in joined presentations and in discussions, and these activities were less used for reasons of students' absence and different groups learning pace. This observation aligns with previously presented notion of the importance of experientially anchored instruction (i.e. instruction based on students' experiences) in the induction of higher degree of transformation (Pugh et al., 2021).

The conceptual change process of the unit's learners toward the scientifically acceptable model of evolution

The second research question: "*If and to what extent the learners of the online evolution teaching unit experience a conceptual change toward the scientifically acceptable model?*" is answered affirmatively by the finding that most of the students who completed above 80% of unit, held a scientific view of evolution. The extent of the change was presented by the finding that depending on the unit's completion rates, 58%-75% of the students who completed above 80% of unit, went through a process of conceptual change. The hypothesis of "*learning evolution using the unit would result in a conceptual change toward the scientifically acceptable conceptual model regarding biological evolution*" is largely validated, with the reservation of its dependence on above 80% completion of the unit's tasks. Interestingly, this concept that connects the unit's completion to reaching the scientific view of evolution gets a second reinforcement from the comparison of student A's and student B's characterization of the learning processes. These results indicate that the relationship between completing the unit and achieving the scientific view of evolution is not merely a matter of increasing the number of answered questions, rather, it is indicative of cognitive engagement. Cognitive engagement in its psychological sense concerns the investment of cognitive effort to understand, deepening in tasks beyond what is required and choosing to invest precisely in difficult tasks (Sinatra, Heddy, & Lombardi, 2015). The implementation of the TTES model for teaching the subject of evolution in class was previously linked to high levels of engagement (Heddy & Sinatra, 2013; Pugh, Bergstrom, Heddy, et al., 2017). Research suggests that engagement takes a part in overcoming alternative conceptions (Dole & Sinatra, 1998; Heddy & Sinatra, 2013). Indeed, this study results that display the conceptual change as dependent on the unit's completion rates (and the implied cognitive engagement) reflects the notion that the degree of engagement can be used as a predictor of likelihood of conceptual change as was found in Dole's & Sinatra's research (1998).

The results of this study demonstrating that the learners of the online evolution teaching unit experienced conceptual change, are in line with previous research that links the implementation of the TTES model as part of evolution teaching in class to results of conceptual change (Heddy & Sinatra, 2013; Pugh et al., 2010). However, since the transformative influence is implemented through a different medium, the shared results suggests that the online evolution teaching unit is an acceptable implementation medium for promoting conceptual change regarding evolution ideas.

Characteristics of the learners' conceptual change process with the progression of learning evolution through the unit

The third research question was: "*What are the characteristics of the learners' conceptual change process while learning evolution through the unit progresses?*". The question was addressed by using a narrative analysis that applied both a deductive and an inductive approaches and yielded the informative characteristics. The two cases (student A

& student B) enabled to identify specific junctions in the unit's design as perception "tipping points" for conceptual change, a difference in learning investment and a joined scientific perception withdrawal concerning human evolution. The complete review of the unit's learners artifacts resulted in general insights regarding different topics: the role the perception of traits permanence take, the importance of language in conveying the learner's perception; the effect of the learner's perception of mutation's influence; the manifestation of determinism as separate from the understanding of the evolution mechanism and the learners' deliberate omission of extinction, death or fitness in the context of human evolution. This characteristics will be discussed below. My hypothesis was that "*learning evolution using the unit would be characterized by individual routes of conceptual change toward the scientifically acceptable conceptual model regarding biological evolution, with joined patterns*". Given that one of the results of the inductive review of learning patterns and the conceptual change process reflect that the conceptual evolvement and change routes differ among learners, and patterns of consequence are presented, it is sensible to determine that the hypothesis is validated.

Characteristics of the learners' conceptual change process:

Conceptual evolvement and conceptual change.

I specifically do not claim or even hypothesize that the "tipping points" which were identified by results as material to student A's conceptual change, are responsible for the conceptual change of all the students that learn through the unit, since the results reflect that the points in which such a change is manifested, differ among the students. These findings make sense for several reasons. The first of which relates to the structure of knowledge. When taking into account the *knowledge in pieces* theory of learning (Smith III et al., 1994), one should expect a different learning path for each student despite the shared experiences, and the same digital environment characteristics. Simply because every one of the students probably begins the learning process through the unit with a somewhat different knowledge structure. This assumption is based on the notion that knowledge is a complex system involving numerous elements of different types, that are continuously refined by experience (Smith III et al., 1994). Since every learning experience a student haves is a part of an experiential continuum (J. Dewey, 1986), it stands to reason that every student's knowledge structure, which integrated and refined a unique set of experiences during each student's life, will be unique. Furthermore, each student has reached the learning process after learning for many years, from different sources, and in different contexts. The influence of prior knowledge on learning is known for its importance for many years (Ausubel et al., 1968). Because of the uniqueness of the personal knowledge structure, the interaction between the structure of knowledge and new elements is expected to be unique, hence the conceptual change of each of the students is also expected to be unique. I suspect that the influence of other aspects (e.g. behavioral, affective), the TTES model is elaborately designed to involve, have on learning, also contribute to that unique route of conceptual evolvement and conceptual change.

Trait permanence is a fundamental issue.

The results signaled the appearance of the perception of trait permanence in a text of a student that formerly presented an alternative (transformative) view of evolution (i.e. organism's traits change), as a marker of conceptual change toward a scientific (variational) view of evolution. This characteristic make sense if we examine its underlying perception of essentialism. Let us say that a student holds to an essence-based alternative conception that an organism's properties are determined by its kind, which is determined by its parents, and that this organism's traits, that are based on its internal "essence" are inherited (Shtulman, 2006). Such a student may hold a view of unity of organisms of the same species that shares an internal essence (which negate the idea of variation). Such a student, when learning about evolution and changes in species, is likely to adopt an alternative view of evolution in which the essence is changing, thus the organism itself transforms (Shtulman & Calabi, 2012). Since the conception of trait permanence negates the essentialistic view of evolution (i.e. if a species evolve, and its trait are permanent, it cannot transform), it stand to reason that the appearance of a perception of trait permanence in a text will signify a conceptual change toward a scientific (variational) view of evolution.

Language is very important.

The results emphasize the need to take into account the difference between spoken language and written scientific language. The students generally express their intentions and thoughts in everyday language. This situation calls for extremely careful interpretations for research purposes. It was demonstrated before that the scientific language itself is a barrier for understanding evolution, even more so when we try to interpret the students' written texts (Nieswandt & Bellomo, 2009). When we wish to ascertain the exact meaning behind the words, perhaps there is room for clarification questions. It could be that this difficulty points in favor of conducting oral interviews or even allowing the possibility of recording answers for follow up questions that are designed to make clear ambiguous phrases. Another option would be to use the digital medium to guide students to the correct scientific phrasing. On the other hand, ambiguous phrasings could serve as a signal to draw our attention to a learning juncture that could potentially benefit from a teachers assistance.

Influence of mutations.

The results draw attention to a perception some students express, in which a mutation can effect an organism by actively changing the organism's phenotype during that organism's lifetime. This is not a novel notion. The so called "mutation power" to transform an entire organism in its lifetime was presented many times by science fiction media (e.g. the hulk, the spiderman films etc.), and is known to result in this specific alternative conception (Bixler, 2007). However, the students alternative conception regarding mutations creates a false biological basis for an evolution alternative conception, that perceives evolution as a process that takes place through organism's transformation rather than through natural selection and variation. This is a known alternative conception that interfere with evolution comprehension (Gregory, 2009; Pobiner, 2016; Shtulman, 2006; Shtulman & Calabi, 2012). Another prevalent alternative conception sees mutation as necessarily detrimental to fitness (Alters & Nelson, 2002; M. U. Smith, 2010). It is my contention that the identified students alternative conception regarding mutations is in line with the known alternative conception of organism transformation, and even deepens it.

The false biological basis that the students' alternative conception regarding mutations offers, may support alternative reasoning by supplying an underlying pseudo-mechanistic explanation for organism's transformation. for example taking the alternative essentialistic point of view, a mutation may be perceived as changing the organism's essence, and thus its traits.

Determinism.

The results pointed to a common alternative conception that is the belief that an organism have its traits due to their necessary function or role in its survival. This is a known alternative conception, that perceives the evolution process as expressing intent and directionality (Gregory, 2009; Pobiner, 2016; M. U. Smith, 2010), which this finding is in line with. Interestingly, as opposed to other alternative conceptions, this alternative conception is present even when the evolution mechanism is understood by the students. It does not seem to hinder perceiving the evolution process in the population level, nor does it interfere with understanding evolution as a long process of population change. It does prevent grasping the evolution mechanism as random and unintentional and as observed before, for students who do not have a fully developed scientific view of evolution, it is expressed as teleology (Pobiner, 2016).

Human evolution is an issue.

In this study an interesting novel phenomenon was revealed. All the students seem to have a major difficulty engaging with the concept of natural selection of humans as part of learning about human evolution. This difficulty may have led to alternative explanations that were either not evolution related or nonscientific. Specifically they included a direct environmental influence on a trait of an individual organism, which is a known alternative conception (Shtulman, 2006; Shtulman & Calabi, 2012).

Subunit 6 of the online evolution unit rehearses all the learned concepts of the unit, and attempts to integrate them with the various levels of organization, and uses human evolution as practice.

Teaching human evolution to adolescent students was previously reported to be perceived as an enjoyable, engaging, and effective way to teach core evolutionary concepts, due to the subject relevance, and the enormous self-interest of adolescents (Pobiner, 2016, p. 262). However, the results attesting to an omission of reference to the concept of natural selection in humans hints to underlying issues (perhaps emotional, psychological, or even cultural) that might have a role in that learning behavior, that need to be recognized and attended to.

As stated above, here it was found that students avoided relating to the mechanism of evolution in the context of humans. This finding may stem from the somewhat scary psychological element that deter humans from confronting the finality of our lives, or in other words – the human fear of death. Death perception matures, which means including all its complex subcomponent (Inevitability, Universality or applicability, Irreversibility or finality, Cessation or nonfunctionality and Causation), by the average age of 7-10 (Slaughter & Griffiths, 2007). Yet fear of death was found as early as in three years old children, which means the fear precedes the mature understanding (Menzies & Menzies, 2018). In fact, it is suggested that this preconceived fear is an evolutionary preserved trait due to its adaptive value that has served us humans as a species from our own risk-averse nature (Menzies & Menzies, 2018). This fear or anxiety is reported to decrease with the full maturation of the death concept (Slaughter & Griffiths, 2007), but it does not fade. The death concept is very present in adolescence, so much that it is referred to as the "elephant of adolescence" (Maurer, 1964, p. 75). The response to this fear, intriguingly, is joint to all the ages: "The most fundamental way that humans appear to respond to death is denial" (Menzies & Menzies, 2018, p. 28), and denial may lead to avoidance (Edelstein, Nathanson, & Stone, 2013). The mechanism of human evolution involves ideas that might trigger the human fear of death. For example, the fact that selection occurs in the population level denounces the attribution of meaning to the death in the individual level. Another hard concept to deal with is the loss of control over life and death incidents that seem to randomly happen and are beyond our reach. On top of all, is realizing that dying from natural selection has a deep meaning of low fitness. Yet, denial is just the first stage of dealing with death. Denial may evolve to better coping mechanisms such as attachments, social support, social identity and suitable cultural worldview, with suitable exposure

(Menzies & Menzies, 2018). Thus exposing to the subject of death through human evolution could in fact be helping, or at least, not expected to cause harm. Nonetheless, thought should be invested in finding a supporting way to assist the learners to deal with that issue and of properly learning the subject of human evolution.

Another factor that might have contributed to the reason students avoid relating to the mechanism of evolution in the context of humans, is the difficulty of transfer. Transfer is the concept of "learn-it-here, apply-it-there" (Perkins & Salomon, 2012, p. 249), but transfer is not simple. It requires the learner to deeply understand the learned material in its original context, to *detect* the connections to the previous content, to *elect* to participate in the new activity, and to *connect* the previously learned content to its new context (Perkins & Salomon, 2012). This endeavor requires motivation, especially for the elect part. The AU quality sometimes is referred to as motivated use. Motivated use in the *elect* context refers to making the choice to use content knowledge as a lens to see and understand the world in new ways (Pugh et al., 2021). And here the two notions combine – there is evidence suggesting that fear may prompt denial and undermine motivation (Putwain & Remedios, 2014; Ruiter, Abraham, & Kok, 2001). My hypothesis is that one possible reason leading to avoidance of dealing with natural selection as part of the human evolution mechanism, is that denial and its consequential avoidance, derived from psychological elements may deter humans from confronting their finality, hinder the motivation to properly transfer the previously learned content (i.e. natural selection) to the new setting of human evolution.

LIMITATIONS

One limitation of this research is it's reduced sample size, that interferes with the possibility to generalize the research findings. Hence, the findings presented in this thesis are valid for this work only, as a typical case. However, I wish to state that the fact that the evidence shows that the learners of this TTES based online unit have taken part in transformative experiences and went through a conceptual change toward the scientific view of evolution, to various degrees, constitutes proof of concept for the unit's design and medium influence.

It should be taken into consideration that this research was performed during a pandemic. One of the Covid19 pandemic consequences was home quarantines. The unit was learned sporadically, sometimes at the students homes. It is hard to estimate the impact of this situation on the students worldview, their willingness to harbor new ideas, and look at the world with "new eyes", to find meaning and value in learning activities and also to find availability to implement the ideas in their very changed lives. In that regard perhaps one should take into account the enveloping situation as well, and treat the existing evidence and results of transformative influence as reflecting the unit's influence in conditions of disrupted learning continuity.

IMPLICATIONS

In this study, the TTES model, which is a complicated teaching model for implementation, was made accessible for teachers and students, using a design tailored to the digital medium, that enabled an in-depth teaching and learning of evolution. It is worth considering the possibility of making complex, but useful models accessible (which may have previously been abandoned due to difficulty in implementing or due to other limitations) through the digital medium.

As stated before, many signs attest to a widespread growth of virtual learning in K-12 contexts, as to the migration of instruction from conventional to digital media. The use of online learning served an important purpose during the recent Covid-19 pandemic

(Reuge et al., 2021) that led to school closing all over the world. However, the repercussions of the pandemic on K-12 students are only beginning to clear up. One clear message is the needed emphasis on social-emotional development (Darling-Hammond et al., 2020). Since this recommendation coexists with the continued use of virtual learning, it is important to combine the social-emotional elements in the virtual learning. Not as a replacement for the physical and social environment, but as an enhancement of this important aspect in an already existing and used medium. This study presents a design that was deliberately planned to nurture a fuller learning experience that includes affective and behavioral aspects, and resulted in evidence of influence on the students scientific world view of evolution, as well as on their perceived value of learning and of the new world view for their everyday life. Thus, exemplifying the practicability of doing so.

Other implications refer specifically to the learning process of evolution itself. It is intended for teachers and learning material designers and is comprised of suggestions stemming from the characterization of the conceptual change process, namely the expected different perceptual evolvement processes of different students. The suggestions are as follows: examine the utility of coupling physical or virtual simulation of a phenomenon and learning of the phenomenon manifestation in reality for the student's comprehension. Take notice of the specific words a student uses for describing an idea, but assume meaning based on several different references to that same idea. Clarify with the students their ideas regarding the way a mutation manifests in an organism, and the origin of their perceptions. Notice the student's relation to trait permanence as a marker of holding the scientific or the alternative point of view of evolution. Look for the alternative conception of determinism, even for students who express the correct evolution process and understanding of main evolution concepts (e.g. adaptation, fitness, etc.), and when it comes to human evolution – tread lightly, knowing there could be other factors influencing their perception.

FUTURE RESEARCH

This research presented evidence of a conceptual change toward the scientific view of evolution among learners of the unit, and evidence of unit's learners who reached the scientific view of evolution dependent on the unit's completion rates. A future research as to the reasons for partially completing the unit, is mandated. As mentioned in the discussion, the relationship between completing the unit and achieving the scientific view of evolution is indicative of cognitive engagement. Since every dimension of engagement usually includes self-regulatory constructs (Sinatra et al., 2015), and since self-regulated learning plays a particularly important part in successful online learning (Feldman-Maggor, Blonder, & Tuvi-Arad, 2021), further research as to the role self-regulation plays in achieving high unit's completion rates may contribute to a possible future design of the unit.

In this thesis, my objective was to explore the transformative influence of the unit, which was developed and used for teaching evolution to high school biology majors, on their conceptions of biological evolution. The results show the unit influences the learners. It induces a transformative process, and it leads its diligent learners toward the scientific view of evolution, sometimes through the process of conceptual change. This evidence can be used as proof of concept for the feasibility of using such a unit as a transformative experience medium, and render, a future design research that may polish the adjustment of the TTES implementation strategies for the digital medium, conducted in a large and diverse sample, worthy. Additionally, this research's online teaching unit was developed using design strategies which express the cognitive, behavioral and affective learning aspects. Further research that takes emotional, behavioral and affective classroom strategies into virtual environments, and examines their effect on learning may expand our understanding of learning and teaching through the digital medium.

Human evolution is an issue**.** The results exposed an interesting phenomenon that I believe worth researching. The students seem to experience a difficulty to engage with the concept of natural selection in humans as part of human evolution. My hypothesis for one of the reasons leading to avoidance of dealing with natural selection as part of the human evolution mechanism, is that denial, derived from psychological elements deterring humans from confronting their finality (Menzies & Menzies, 2018), hinder the motivation (Putwain & Remedios, 2014; Ruiter et al., 2001) to properly transfer the previously learned content (i.e. natural selection) to the new setting of human evolution. It is interesting to learn more about this phenomenon. Other occurrences of this phenomenon (e.g., how did Darwin offer the concept of natural selection for humans? Where there any difficulties involved? Have human evolution researchers experience such difficulties?), and a research characterizing the difficulties of transfer in the context of human evolution, may contribute to our understanding of this phenomenon. Also, since denial may evolve to better coping mechanisms such as attachments, social support, social identity and suitable cultural worldview (Menzies & Menzies, 2018), another line of research may explore the possible strategies to support coping with denial, and their possible adjustments to a digital learning environment.

Epilogue

The whole basis for learning is assigning personal meaning and value to experiences, and awarding a personal interpretation to the world, as it is perceived through our senses, and all of our experiences.

It seems to me that as human beings, learning in a holistic way that nurtures our emotional positions, the meaning and value that we find, and the way we perceive and interpret the world is natural for us. If this notion is indeed correct, then all that remains to be done is to kindle our inherent need for learning, to supply a trusted and safe environment that will allow us to express our opinions, that will make room for our emotions, and that will expand our perceptions in a way that will serve our development.

It's hard to believe that interacting with a computer can profoundly influence our worldview. However, this interaction seem to be able to do so. If the said interaction is built to produce an authentic dialogue between the learner's perceptions and the perceptions presented, if it is built in consecutive steps that allow and even encourage the incorporation of the learner’s expanding worldview with the learner’s authentic everyday experiences, and if it is built to validate the learner’s emotions and values.

Evolution is a gateway to the 21st century and its biology. I used an online computer unit to teach evolution. Now in Covid as the world transitions to more and more Information and Communications Technology we need to find a way in which interacting with the computer will not disconnect us from our daily experiences, because these are related to the meaning that we give to things and even the world, and meaningless learning has no purpose.

In reaching scientific and meaningful worldview for the learners, we will pave the way for scientific literacy, which is a significant goal in science education.

ACKNOWLEDGMENTS

The need to understand the nature of reality is shared by many. Our worldview is built through our experiences of the world, as well as our interpretation of these experiences and our memory of them. It is an everchanging, profoundly complex structure. My own need to learn about the nature of reality led me ever since I could remember myself (as a little girl…), and grew stronger with the years and the understanding that my learning, beyond enriching myself, may serve others. Yet, developing the skill set required for learning about science education, in a way that will contribute to others (i.e. learning to perform research), required learning of its own. Many experiences molded my learning – fascinating lectures, discussions, courses, articles, and my own continuous effort to iteratively view reality through different content lenses.

Many are responsible for my advancement, as is expressed by this thesis, but I particularly wish to name two. First and foremost my advisor, prof. Anat Yarden. Anat, two years ago you invited me to join an amazing group of researchers, led by you. The two years that followed were a journey involving expanding a prior research, triumphing personal difficulties, planning, designing and executing a research during a worldwide pandemic, and getting to know the academic world. I wish to thank you for your leadership, but most of all for your compassion. You gave me the best conditions to pursue a better understanding, to create, and evolve as a researcher, and your nurturing attitude especially in times of familial difficulty made a world of a difference to me. Second, I wish to thank Dr. Gilat Brill. Gilat, thank you for coming aboard. You accompanied my learning process for several years now, and every interaction we have is valuable, widens my perception, and pushes me to use my expanded view individually. As I have claimed before, our synergy has transformative characteristics. Both of you showed me the way forward in many ways.

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> *"This experiment must play out.*
>
> *And it will."*
>
> Out of: A moment (2002)
> A little girl pulls a tablecloth (In Hebrew)
> Wisława Szymborska

APPENDIX A: THE PERCEPTION BOARD REPRESENTATION

Perception	1	2	3	4	5	Perception
Individual differences are fodder for selection						Individual differences are minor and non-adaptive
A trait's hereditability depends upon its adaptive value						A trait's hereditability depends upon its origin
Differential survival/reproduction is irrelevant to adaptation						Differential survival/reproduction produces adaptation
Species are domesticated via changes to individual organisms						Species are domesticated via selective breeding
Adaptation is more common than extinction						Extinction is more common than adaptation

APPENDIX B: EVOLUTIONARY REASONING SCALE

1. Imagine that biologists discover a new species of woodpecker that lives in isolation on some secluded island. These woodpeckers have on average, a 1.0 inch beak, and their only food source is a tree-dwelling insect that lives on average, 1.5 inches under the tree bark. Compared to its parents, the offspring of any two woodpeckers will grow to have:

a. A longer beak.

b. A shorter beak.

c. Either a longer or shorter beak: neither outcome is more likely.

2. In studying the birds, the biologists notice that only a small percentage reproduce each year. They therefore predict that, compared to populations in which the majority of birds reproduce each year, this population will adapt to its environment:

a. Faster.

b. Slower.

c. Either faster or slower; neither outcome is more likely.

3. The biologists clip the wing feathers of some of the birds, rendering them unable to fly. Compared to the offspring of the other woodpeckers, the offspring of those with clipped wings will be born with:

a. Longer wing feathers.

b. Shorter wing feathers.

c. Either longer or shorter wing feathers; neither outcome is more likely.

4. Imagine that biologists re-measure the birds' beaks in 2111 and discover that the average beak length has increased from 1.0 inches to 1.5 inches over the last hundred years. Nevertheless, some of the birds still have beaks that are shorter than 1.5 inches. These birds most likely descended from which of the following groups of birds alive one hundred years ago?

a. Birds with shorter-than-average beaks.

b. Birds with longer-than-average beaks.

c. Birds with either shorter-than-average beaks or longer-than-average beaks; neither possibility is more likely.

5. Suppose that the pair of woodpeckers migrates to a different island with fewer trees and more wind. As a consequence of flying in a windier environment, both woodpeckers develop stronger wing muscles. Compared to the offspring of the woodpeckers on the original island, the offspring of these two woodpeckers will be born with:

a. Stronger wing muscles.

b. Weaker wing muscles.

c. Either stronger or weaker wing muscles; neither outcome is more likely.

6. Corn is an entirely artificial food. Over a period of thousands of years, Native Americans purposefully transformed maize through special cultivation techniques, modifying corn from wild grass (teosinte) which grew in Central America 7,000 years ago.

In contrast to modern maize, which yields hundreds of plump kernels per cob, each Teosinte plant yielded a handful of small kernels. Would it be possible to cultivate corn back into a plant like Teosinte?

a. Yes

b. No

c. More information is needed

7. Select the "odd man out."

a. Corn selectively bred to produce purple kernels.

b. Corn genetically engineered to produce purple kernels.

c. Corn grown in a special soil to produce purple kernels.

8. Humans and Chimpanzees share a common ancestor, which lived around 6 million years ago. Do you think this ancient primate was more genetically similar to modern day humans or modern chimpanzees?

a. Humans.

b. Chimpanzees.

c. Either humans or chimpanzees; neither is more likely.

9. Do you think the last common ancestor of humans and chimpanzees was more genetically similar to modern day humans or modern day gorillas?

a. Humans.

b. Gorillas.

c. Either humans or gorillas; neither is more likely.

10. Which of the following organisms also share a common ancestor with humans? (Circle all that apply)

a. Elephants

b. Lemurs

c. Salamanders

d. Sparrows

e. Bees

f. Jellyfish

g. Algae

h. Daffodils

i. Brontosaurus

11. As chimpanzees continue to evolve, do you think they will become more or less similar to modern day humans.

a. More similar.

b. Less similar.

c. Either more or less similar; neither outcome is more likely.

12. If chimpanzees and humans could produce fertile offspring (i.e., offspring that could eventually produce offspring of its own), should they be considered separate species?

a. Yes

b. No

c. More information is needed

13. Do you think that the number of extinct bacteria species is greater or smaller than the number of living bacteria species?

a. Greater.

b. Smaller.

c. Either greater or smaller; neither possibility is more likely.

14. Do you think the number of bacteria species in existence ten million years from now will be greater or smaller than the number of bacteria species in existence today?

a. Greater.

b. Smaller.

c. Either greater or smaller; neither possibility is more likely.

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APPENDIX C: TRANSFORMATIVE EXPERIENCE SURVEY

Think about the ideas you've learned in this study and please indicate how much you agree or disagree with each of the following by this scale:

(6) Strongly Agree

(5) Moderately Agree

(4) Slightly Agree

(3) Slightly Disagree

(2) Moderately Disagree

(1) Strongly Disagree

TTES QUALITY: AU (ACTIVE USE)

(1) During this study I talked about the evolution ideas I have learned.

(2) I talked about the evolution ideas I've learned outside of this study.

(3) I talked about the evolution ideas I've learned just for fun.

(4) During this study I thought about the evolution ideas.

(5) I thought about the evolution ideas outside of this study.

(6) I used the evolution ideas I've learned in my everyday experience.

(7) I used the evolution ideas even when I didn't have to.

(8) I sought out opportunities to use the evolution ideas I've learned.

(9) I looked for examples of the evolution ideas in TV shows, movies, or books.

TTES QUALITY: EP (EXPANSION OF PERCEPTION)

(10) During this study, I thought about the research evolution ideas differently.

(11) The evolution ideas changed the way I view situations.

(12) I think about experiences differently now that I have learned these evolution ideas.

(13) I can't help but to think about the evolution ideas I've learned.

(14) The evolution ideas I have learned changed the way I think about situations that occur in TV shows, movies, or books.

TTES QUALITY: EV (EXPERIENTIAL VALUE)

(15) I found it interesting to learn about the evolution ideas.

(16) I found it interesting to think about the evolution ideas outside of class.

(17) The evolution ideas I learned are valuable in my everyday life.

(18) The evolution ideas I learned make my out-of-class experience more meaningful.

(19) The evolution ideas make my life more interesting.

(20) The evolution ideas make TV shows, movies, or books more interesting.

(21) Give an example of how you used or thought about the evolution ideas you learned.

(22) Given an example of how your experiences have changed due to learning the evolution ideas.

(23) Give an example of how you may value the evolution ideas you have learned.

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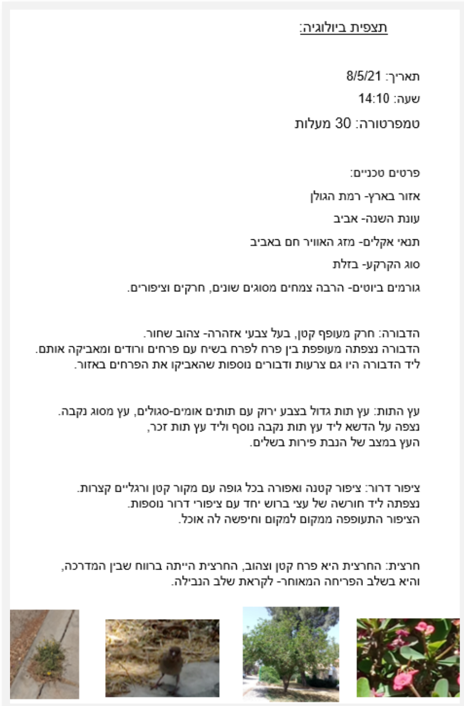
APPENDIX D – Student A's & student B's submissions

Subunit 2 student A



תצפית ביולוגיה:

תאריך: 8/5/21

שעה: 14:10

טמפרטורה: 30 מעלות

פרטים טכניים:

אזור בארץ- רמת הגולן

עונת השנה- אביב

תנאי אקלים- מזג האוויר חם באביב

סוג הקרקע- בזלת

גורמים ביוטים- הרבה צמחים מסוגים שונים, חרקים וציפורים.

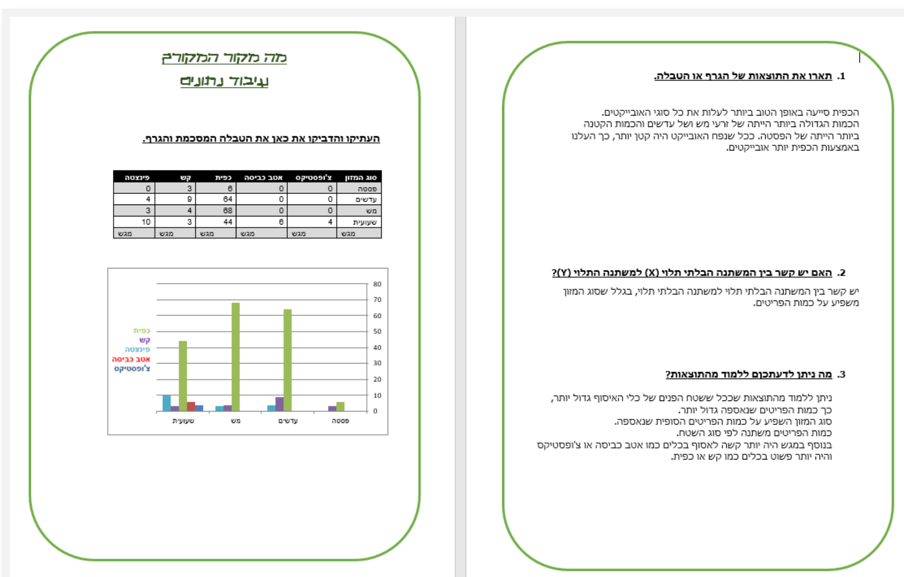
הדבורה: חרק מעופף קטן, בעל צבעי אזהרה- צהוב שחור.
הדבורה נצפתה מעופפת בין פרח לפרח בשיח עם פרחים ורודים ומאביקה אותם.
ליד הדבורה היו גם צרעות ודבורים נוספות שהאביקו את הפרחים באזור.

עץ התות: עץ תות גדול בצבע ירוק עם תותים אומים-סגולים, עץ מסוג נקבה.
נצפה על הדשא ליד עץ תות נקבה נוסף וליד עץ תות זכר,
העץ במצב של הנבת פירות בשלים.

ציפור דרור: ציפור קטנה ואפורה בכל גופה עם מקור קטן ורגליים קצרות.
נצפתה ליד חורשה של עצי ברוש יחד עם ציפורי דרור נוספות.
הציפור התעופפה ממקום למקום וחיפשה לה אוכל.

חרצית: החרצית היא פרח קטן וצהוב, החרצית הייתה ברווח שבין המדרכה,
והיא בשלב הפריחה המאוחר- לקראת שלב הנבילה.

Subunit 3 student A



מה מקור המקורים

עיבוד נתונים

העתיקו והדביקו את כאן את הטבלה המסכמת והגרף.

סוג המזון	צ'ופסטיקס	אטב כביסה	כפית	קש	פינצטה
פסטה	0	0	6	3	0
עדשים	0	0	64	9	4
מש	0	0	68	4	3
שעועית	4	6	44	3	10
מגש	מגש	מגש	מגש	מגש	מגש

1. **תארו את התוצאות של הגרף או הטבלה.**

הכפית סייעה באופן הטוב ביותר לעלות את כל סוגי האובייקטים.
הכמות הגדולה ביותר הייתה של זרעי מש ושל עדשים והכמות הקטנה
ביותר הייתה של הפסטה. ככל שנפח האובייקט היה קטן יותר, כך העלנו
באמצעות הכפית יותר אובייקטים.

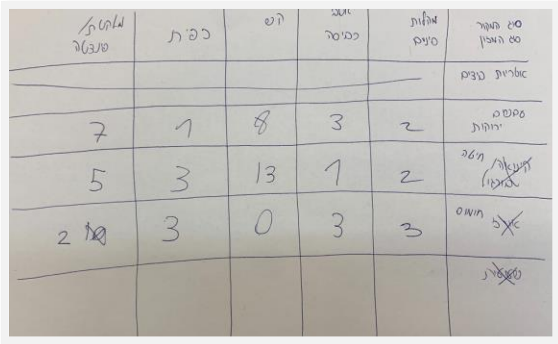
2. **האם יש קשר בין המשתנה הבלתי תלוי (X) למשתנה התלוי (Y)?**

יש קשר בין המשתנה הבלתי תלוי למשתנה הבלתי תלוי, בגלל שסוג המזון
משפיע על כמות הפריטים.

3. **מה ניתן לדעתכם ללמוד מהתוצאות?**

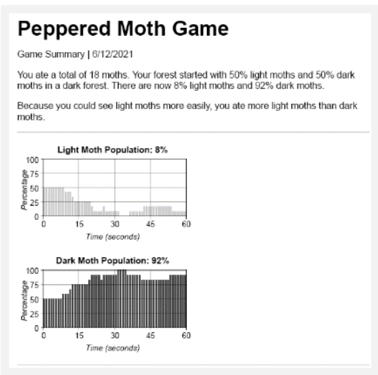
ניתן ללמוד מהתוצאות שככל ששטח הפנים של כלי האיסוף גדול יותר,
כך כמות הפריטים שנאספה גדול יותר.
סוג המזון השפיע על כמות הפריטים הסופית שנאספה.
כמות הפריטים משתנה לפי סוג השטח.
בנוסף במגש היה יותר קשה לאסוף בכלים כמו אטב כביסה או צ'ופסטיקס
והיה יותר פשוט בכלים כמו קש או כפית.

Subunit 3 student B



Subunit 4

Student A black forest



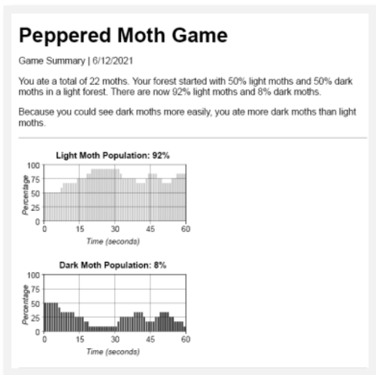
Peppered Moth Game

Game Summary | 6/12/2021

You ate a total of 18 moths. Your forest started with 50% light moths and 50% dark moths in a dark forest. There are now 8% light moths and 92% dark moths.

Because you could see light moths more easily, you ate more light moths than dark moths.

Student A white forest



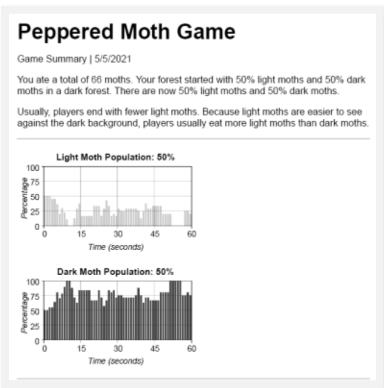
Peppered Moth Game

Game Summary | 6/12/2021

You ate a total of 22 moths. Your forest started with 50% light moths and 50% dark moths in a light forest. There are now 92% light moths and 8% dark moths.

Because you could see dark moths more easily, you ate more dark moths than light moths.

Student B black forest



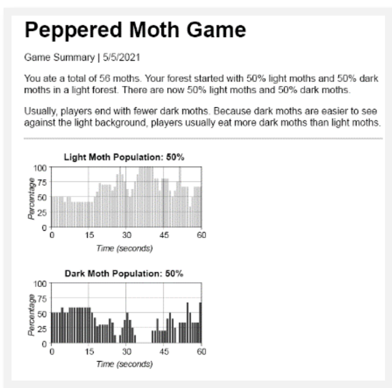
Peppered Moth Game

Game Summary | 5/5/2021

You ate a total of 66 moths. Your forest started with 50% light moths and 50% dark moths in a dark forest. There are now 50% light moths and 50% dark moths.

Usually, players end with fewer light moths. Because light moths are easier to see against the dark background, players usually eat more light moths than dark moths.

Student B white forest



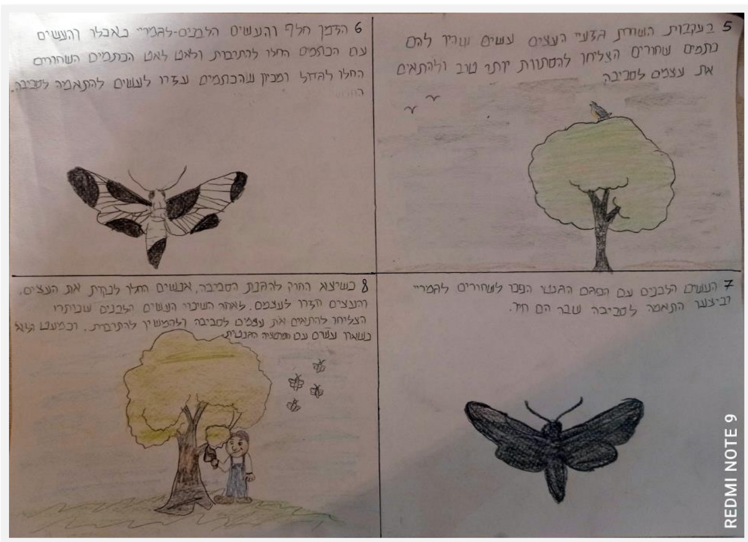
Peppered Moth Game

Game Summary | 5/5/2021

You ate a total of 56 moths. Your forest started with 50% light moths and 50% dark moths in a light forest. There are now 50% light moths and 50% dark moths.

Usually, players end with fewer dark moths. Because dark moths are easier to see against the light background, players usually eat more dark moths than light moths.

Subunit 5 student A



Subunit 6 student A

<u>אפליה על רקע צבע עור</u>

אפליה על בסיס צבע עור, לדעתי מעידה על בורות חמורה ותפיסת עולם ישנה.
אחרי הכל כבר מאות שנים קיימת גזענות על בסיס צבע עור.
אנשים "לבנים" שהשפילו והתייחסו באופן מזעזע לאנשים "שחורים"
רק בגלל שלאנשים בעליי צבע עור שחור יש יותר יצור של מלנין.
אם היינו בתקופות קדומות, אז אנשים בעליי צבע עור קהה שהיו
נודדים למדינות קרות כנראה לא היו שורדים או שהם היו מבצעים
התאמה לסביבה והעור שלהם היה אחריי כמה דורות מבהיר.
אך דברים כאלה קורים גם היום, אלה דברים
שנמצאים בתת מודע שלנו רק בגלל תפיסות של העולם הישן ואלה
דברים שמביאים לפגיעה באנשים אחרים רק מתוך בורות.

APPENDIX E – Article - Making conceptual change last: learning evolution through the teaching for transformative experiences in science (TTES) model leads to knowledge retention over time

ABSTRACT

Maintaining a scientific evolutionary worldview is imperative for science literacy, and for academic development and research in science, yet it is seldom a given. Obtaining a scientific evolutionary worldview is challenging, as manifested by the high prevalence of alternative conceptions among students from all education levels. Research evidence positions the teaching for transformative experiences in science (TTES) model as effective in facilitating conceptual change, and in raising levels of interest, efficacy, engagement, and enjoyment. The purpose of this study was to assess the conceptual change that follows use of the TTES model, as well as to evaluate the short- and long-term retention of the acquired scientific evolutionary worldview. The perceptual development and evolutionary worldview of 10 secondary-school students were followed for 3 years, using a variety of questionnaires and narrative analysis of students' artifacts before, during and after a 4-week evolution-teaching intervention. Our findings confirm that a transformative process took place, and demonstrate a fundamental change in students' perceptions, which was maintained for 1 month after teaching, and 2 years later. We propose that the TTES model evokes self-initiated retrieval, a key component of the knowledge-retention mechanism. We call for further research on the proposed mechanism and suggest using the TTES model as a vehicle toward maintaining a scientific evolutionary worldview.

KEYWORDS evolution, conceptual change, knowledge retention, worldview, retrieval, science education

1 INTRODUCTION

1.1 Learning evolution and alternative conceptions

There is overwhelming acceptance among scientists and science education organizations of the veracity and centrality of evolution and its power in unifying the sciences; it is especially important in biology (Pobiner, 2016, p. 232), where evolution is a core concept (Coley & Tanner, 2015). In fact, a complete understanding of modern biology cannot be achieved without understanding evolution (Bishop & Anderson, 1990, p. 415). The documentation of significant difficulties in understanding and accepting the theory of evolution is therefore quite worrisome. These difficulties are often expressed in a variety of alternative conceptions (Bishop & Anderson, 1990; Flanagan & Roseman, 2011; Gregory, 2009; Shtulman, 2006; Sinatra et al., 2008; M. U. Smith, 2010), which are highly prevalent among the public and students from all levels of education (Pobiner, 2016). An alternative conception is defined as the understanding of a real-world phenomenon in a way that is not consistent with the scientific explanation or model of that phenomenon (Modell et al., 2005). An example alternative conception is the claim that organisms have an essence (essentialism), and that changes in a population indicate organism transformation and a change in essence; this transformational point of view, as opposed to the scientifically accepted variational view of evolution, disregards major aspects of evolution and therefore hinders comprehension of evolution (Bishop & Anderson, 1990; Shtulman, 2006; Shtulman & Calabi, 2012). Indeed, students' alternative conceptions have been identified as a significant impediment to conceptualizing, understanding, and building correct scientific models, as well as to accepting the theory of evolution (Pobiner, 2016; Sinatra et al., 2008; M. U. Smith, 2010). It seems clear that attending to students' particular alternative conceptions during instruction is imperative to the successful learning of evolution.

1.2 Conceptual change models

For many years, the dominant working model for dealing with alternative conceptions, while providing the theoretical foundation required to explain instances of conceptual change (Demastes et al., 1996), was the conceptual change model (CCM) (Posner et al., 1982). This model was based on Piaget's process of accommodation (Huitt & Hummel, 2003) and regarded conceptual change as a process of concept substitution. The main strategy of the CCM involved characterizing a concept's stature, undermining that concept's position, and offering the students a scientifically accepted rival concept, with a higher status, to invoke substitution. The CCM was extensively researched and proven effective in promoting conceptual change (Pugh et al., 2010). However, advances in the perception of cognitive structure, which characterizes concepts as complex clusters of ideas that are bound together rather than independent separate units, challenged the mechanism suggested by the CCM. From this perspective, a learning process that consists of replacing perceptions was deemed less valid. The notion of substitution also conflicts with the constructivist idea that learning is an adaptation of prior knowledge. Pieces of knowledge that are abandoned with the substitution could therefore not be used as a learning resource (Smith III et al., 1994).

Smith III et al. (1994), who proposed the constructivist theory of knowledge in pieces, offered a theoretical perspective that viewed conceptual change as a process of knowledge refinement and reorganization. The authors perceived students' conceptions as material for the conceptual change process, and the process itself as a development within a complex system.

Other theories added motivational and affective dimensions to the conceptual change process. Dole and Sinatra's Dole and Sinatra (1998) cognitive reconstruction of knowledge model combined critical elements from cognitive psychology, science education, and social psychology. The model characterized the interaction between an input message and the learners, while considering the learners' existing conceptions and their motivation to process the information in the received message. They pointed out that strong metacognitive engagement is a key component in enabling long-lasting conceptual change (Dole & Sinatra, 1998). Similar to the cognitive reconstruction of knowledge model, Gregoire (2003) cognitive–affective model of conceptual change considered the message, but it emphasized the psychological viewpoint of the message receiver and the affective appraisal of the message as a step leading to cognitive processing.

An approach that considers both sociocultural and cognitive influences as critical catalysts of conceptual change, and offers a framework that integrates these components, is the belief and knowledge acquisition and change framework (Murphy, 2007). This framework places the learner at the center and explores the relationship between knowledge and belief from an epistemic point of view. According to this framework, the distinction between knowledge and belief is vital for learning, because the process of knowledge acquisition and change proceeds from belief and knowledge as separate constructs to an overlapping construct. Optimal learning is achieved when students' beliefs, which are generally socially enculturated, are integrated with their cognitively reasoned understanding (Murphy, 2007, p. 44).

1.3 Teaching for transformative experiences in science (TTES) model as a facilitator of conceptual change

The TTES model (Pugh & Girod, 2007) was constructed based on Dewey's (1938) theory, which claimed that education should expand the individual perspective beyond classroom experiences to the outside world. This theory delved into the transformative nature of human experiences as a path toward meaningful learning, while emphasizing an aesthetic view of the world as beneficial for the development of a broader view of it (R. E. Dewey, 2012). The TTES model was founded on three qualities: experiential value (EV), expansion of perception (EP), and active or motivated use of concepts (AU) (Pugh & Girod, 2007). EV describes the degree to which the student identifies and appreciates the meaningful contribution of the learned perception/new worldview to his/her personal life experiences. EP describes the degree to which changes in the student's perception broaden and deepen his or her worldview, so that the world is perceived through a content lens and is layered with meaning. AU, also referred to as motivated use (Pugh, Bergstrom, Heddy, et al., 2017), describes the degree to which the student, of his/her own accord and without directive or solicitation, uses learned terms, concepts, and ideas, especially in real-life contexts, i.e., outside the classroom. Since aesthetic understanding enhances the transformative quality of the learning experience by both strengthening the EV and merging the in-school and out-of-school experiences (Girod et al., 2003), it is related to implementation of the model qualities.

The model was processed into an instructional strategy that facilitates transformation and conceptual change while considering the student's prior perception, and aspires to broadening the student's perspective while stimulating awareness of the EV of the subject at hand (Heddy & Sinatra, 2013; Pugh & Girod, 2007; Pugh et al., 2010). Studies implementing the TTES model were conducted with biology undergraduates, high-school students and elementary-school students, and presented significant conceptual change (Girod et al., 2010; Heddy & Sinatra, 2013; Pugh et al., 2010), conceptual understanding (Girod et al., 2010; Pugh, Bergstrom, Heddy, et al., 2017), increased interest and efficacy (Girod et al., 2003; Girod et al., 2010), high levels of engagement (Heddy & Sinatra, 2013; Pugh, Bergstrom, Heddy, et al., 2017), and increased levels of enjoyment (Heddy & Sinatra, 2013).

1.4 TTES and knowledge retention

Retention and/or forgetting are considered natural outcomes and successive processes of meaningful learning. Retention refers to maintenance of the new meaning arising from the new idea's connection to anchoring ideas over time, whereas forgetting refers to the spontaneous and gradual loss of the ability to differentiate the new meanings from their anchoring ideas (obliterative subsumption) (Ausubel, 2000). There is evidence that students tend to retain only the information necessary to pass examinations before reverting back to their original beliefs (Nehm & Schonfeld, 2007), and there is a call for research into the durability of newly acquired scientific conceptions (Georghiades, 2000). In a study examining implementation of the teaching for transformative aesthetic experience model in 5th-grade science lessons, the treatment-class students seemed to forget much less over time than the control-class students (Girod et al., 2010). Those researchers indicated that replication to validate the findings was warranted, and suggested that teaching for transformative aesthetic experiences could be a powerful new pedagogical model for 21st century science teaching and learning (Girod et al., 2010, p. 819).

The present study explores the influence of TTES on facilitating (i) a conceptual change in biological evolution by tracking the students' concepts while learning, and (ii) knowledge retention (preservation of conceptual change over time).

2 RESEARCH QUESTIONS

This study was conducted in two phases. The first phase's research questions related to the TTES model's implementation: (i) Are there indications of a transformative learning process following TTES instruction on concepts of evolution in the participant's unrelated submitted assignments? (ii) Does TTES instruction result in conceptual change toward the scientifically accepted conceptual model of biological evolution? The second phase's research questions related to long-term retention: (iii) Is the conceptual change in evolution understanding following TTES model implementation preserved over time, demonstrating knowledge retention? (iv) Is there a difference in short- and long-term retention of concepts learned using the TTES instruction and concepts learned using traditional teaching methods? (v) Are there any differences in retention among students?

3 METHODS

3.1 Course context

The evolution instruction sequence used in the intervention was derived from the 11th-grade biology ecology curriculum. The intervention's instructional sequence is presented in Table 1a. The evolution instruction sequence used in the control lesson was also derived from the 11th-grade biology ecology curriculum. The control's instructional sequence is presented in Table 1b.

TABLE 1a Intervention evolution instruction sequence

Lesson no.	Content taught using the TTES model	Length (min)
1-2	Organism adaptation to the environment, and types of adaptation Definitions, identification, comparisons, and out-of-school (homework) nature assignment	90
3-4	Lab activity: "Does your beak make you freak?"	90

	Natural selection. The compatibility of an individual attribute and environmental influences: why do they look like that?	
5	A free discussion of students' concepts regarding environmental influence on organismal evolution	45
6	Lab activity: Industrial melanism. Physical simulation, data gathering and statistics	45
7-8	Industrial melanism: from statistical analysis to evolutionary mechanism – putting it all together. Virtual Moth Lab. Discussion.	90
9-10	Lab activity: Variation. Discussion: variation and natural selection; fitness Group workshop: California salamander: "ring species" concept. The creation of species. Summary	90

TABLE 1b Control evolution instruction sequence

Lesson no.	**Content taught using the control classical teaching**	**Length (min)**
1-2	Genetic drift: from reinforcing traits to accidental extinction. Lecture followed by a Q & A session and discussion	90
3-4	Environmental influence: adaptation vs. extinction. Lecture followed by a Q & A session and discussion	90
5-6	Artificial selection: domestication and cultivation. How did humans get from wolfs to dogs?	90

	Lecture followed by a Q & A session and discussion	

The intervention and control instruction were administered consecutively, in the same class, with the same students as an internal control.

3.2 Participants

The student participant population was homogeneous, from middle-class families living in a rural semiarid agricultural region. All students participating in this study (n = 10) were 11th-grade biology majors from one school, 16 to 17 years of age. The group included six female students and four male students.

The main author had served as the group's science and biology teacher from the 7th grade on, and resided in the same geographical region as the students. This author was not acquainted with the students prior to teaching them and maintained only a professional relationship with them. This continued engagement offered several clear advantages, the first being the opportunity to measure students' perceptions from pre-intervention to delayed post-intervention over a long time interval (3 years). The second advantage was maintenance of data integrity, as the intervention evolution concepts were confirmed to not have been taught prior to or after the intervention. For example, from 7th to 9th grade, evolutionary terms were casually used in class as a basis for reasoning without explicit instruction in evolution. In light of the teacher's centrality in influencing students' perceptions of evolution (Yates & Marek, 2014), examining the students in the 10th grade and analyzing them prior to conception implementation laid the foundation for optimal adaptation of the 11th-grade intervention teaching plan to deal with the students' alternative conceptions; while confirming that further evolution teaching (excluding the intervention) did not take place in the time interval between the pre-intervention survey and the actual intervention. The same approach was implemented regarding the post-intervention survey. Another possible advantage was the first author's understanding and familiarity with the students' everyday lives in their shared unique living environment, contributing to the success of the teaching strategy. This allowed for sharing transformative experiences, identifying the students' potential EV for concepts and recognizing objects in the students' environment suitable for the practice of "re-seeing" the world (Pugh, Bergstrom, Heddy, et al., 2017).

The participants are referred to by number (student 1, student 2, and so on). The numbers were assigned randomly at the beginning of the research and retained during the course of the study.

3.3 Materials and measures

3.3.1 The biological evolution literacy (BEL) survey

To measure students' knowledge and alternative conceptions of biological evolution, we used a survey with 23 Likert-scale items adapted from an instrument developed by (Yates & Marek, 2015, p. 816). The BEL survey was administered three times during the research. As a pre-test nearly 1 year prior to the intervention, as a post-test 5 weeks after the intervention, and as a delayed post-test 2 years after the intervention. Participants were asked to agree or disagree with each statement using a 5-point scale ([1] strongly agree to [5] strongly disagree; see Appendix A for the complete survey).

Some changes were made to adapt the original survey to the current research. First, the option of no response was not included, to discourage decision avoidance. Second, the third statement was altered because most biology majors in study country are unfamiliar with thermodynamics concepts. Therefore, the original statement: “According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms” was amended to: “Nature aspires to simplicity. Hence, complex life forms cannot evolve from simpler life forms.”

TABLE 2 Cronbach’s α values for the biological evolution literacy (BEL) survey

BEL survey, 23 statements	n	**r_t**
Pre-test	9	0.4009
Post-test	10	0.9383
Delayed post-test	10	0.7615

The reliability of the BEL survey was high. The low pre-test Cronbach’s α value represents a lack of consistency in the results, reflecting the students’ lack of consistent formal knowledge of the subject. The post-test, which was conducted ca. 1 month after the end of formal teaching, presents a high Cronbach’s α value, reflecting high reliability of the BEL questionnaire, since it indicates the questionnaire’s ability to reflect the students’ knowledge of biological evolution. The delayed post-test, conducted 2 years after the end of teaching, still presents a Cronbach's α value reflecting acceptable internal validity and preserved evolution knowledge. Student 10 was absent and did not take the pre-test.

Two methods of scoring were used for the data analysis. First, the responses were grouped into two categories: "strongly agree" and "somewhat agree" were combined, indicating the participant's inclination to agree with the statement. Similarly, the responses "strongly disagree" and "somewhat disagree" were combined, indicating the participant's inclination to disagree with the statement. The average percentage of students choosing concepts in accordance with the scientifically accepted model of evolution (whether they agreed with a scientifically accepted statement or disagreed with an alternative conception statement) was determined. Second, by means of Likert scaling of the statement responses, a biological evolution conception index was created. Every statement was scored according to its association with the scientifically accepted conceptual model or alternative conception. For statements in which agreement indicated acceptance of a scientifically accepted conceptual model (statements 2, 4, 8, 10, 11, 14, 15, 18, 20, 23), index scoring was as follows: strongly agree, score of 5; somewhat agree, 4; undecided/never heard of it, 3; somewhat disagree, 2; strongly disagree, 1. For statements in which agreement indicated acceptance of an alternative conception (statements 1, 3, 5, 6, 7, 9, 12, 13, 16, 17, 19, 21, 22), index scoring was as follows: strongly agree, 1; somewhat agree, 2; undecided/never heard of it, 3; somewhat disagree, 4; strongly disagree, 5. The individual scoring range of the BEL survey index was 23 to 115. A score of 115 represented the highest level of understanding coupled with a lack of alternative conceptions, whereas a score of 23 represented the lowest level of understanding combined with high levels of alternative conceptions related to biological evolution.

A comparison was made between pre-test, post-test, and delayed post-test results using simple aggregations to establish their improvement or regression. We calculated means, and delta of means. To ascertain significance of the assertions of meaningful distances between test results, we used the Wilcoxon signed-rank test.

Since student 10 was absent for the pre-test, there were no results for this student arising from comparison with the pre-test, thus, lowering n from 10 to 9. However, student 10 was not excluded from the comparison of post-test and delayed post-test results. Student 1's results were different from all other students' results. Student 1's questionnaire demonstrated a drop in achievements after formal teaching and learning (post-test), and a subsequent rise in the delayed post-test. An interview conducted with student 1 after the pre-test, as well as an examination of his verbal participation during class using the lesson transcripts, indicated difficulties in understanding the written test questions. Since this was only apparent with the questionnaire results, we calculated comparisons including student 1's results and in the absence of student 1's results, thus, lowering n from 10 to 9. Taking student 10 into account as well, n = 8. Questionnaire reliability (internal validity) took all 10 students into account.

3.3.2 Perception board

To continuously follow students' perceptions during and after the intervention, we developed a perception board. This instrument enabled us to monitor individual and group patterns of conceptual change toward or away from the scientific perspective of evolution. The perception board framework was adopted from Shtulman's evolutionary reasoning scale (Shtulman, 2006). The scale was used to assess whether participants understood evolution and its various phenomena (adaptation, variation, domestication, etc.) as a transformational or variational change (Table 3). As noted in the introduction, a transformational change is a view of evolution which maintains that species possess an inherent essence, which transforms over time. Various alternative conceptions stem from this view, among them, inheritance of acquired traits, and adaptation led by internal intent. A student who holds a transformational view of evolution may believe that an organism adapts to the environment by changing its traits and that said changes will be passed on to its offspring. A student who holds a variational view of evolution understands that species change through random gene mutations which, over time, cause variations in the population through natural selection. Each view presents an inherently different conceptual understanding of evolution: the variational view is consistent with the scientific perspective and the transformational view is inconsistent with it. In accordance with Shtulman (2006), Heddy and Sinatra (2013) also used this framework to analyze students' survey responses. In contrast, we used this framework to present the students with contradictory views of several evolutionary phenomena, and asked them to continuously evaluate and present their view of each phenomenon.

TABLE 3 Variational (V) and transformational (T) interpretations of the same evolutionary phenomena. Processed from Shtulman (2006, p. 175)

Concepts	Phenomenon	Theory	Interpretation

A	Variation	V	Individual differences are fodder for selection
		T	Individual differences are minor and non-adaptive
B	Inheritance	V	A trait's heritability depends upon its origin
		T	A trait's heritability depends upon its adaptive value
C	Adaptation	V	Differential survival/reproduction produces adaptation
		T	Differential survival/reproduction is irrelevant to adaptation
D	Domestication	V	Species are domesticated via selective breeding
		T	Species are domesticated via changes to individual organisms
E	Extinction	V	Extinction is more common than adaptation
		T	Adaptation is more common than extinction

The contradictory views were placed on opposite sides of a board. Each side of the board included interpretations that represented the variational theory—which stands in line with the scientific view of the phenomenon, and interpretations representing transformational theory. The space between each pair of views was divided into five segments, creating a scale. The students were asked to individually and quietly (without speaking) place their name on that scale as a representation of their perception regarding the views on the board. The students were made aware that they were being appraised for their mere participation, and not their choices, and were urged to express their real opinion even if they thought the teacher expected a different one. We repeated this process several times, for a representation of the change in student's perceptions over time. The board was used to monitor the students' perceptions throughout the intervention and for the month following it. Another board entry was recorded 2 years after the end of the formal teaching unit and is referred to as delayed post (see Appendix B for a representation of the complete perception board).

The perception board assessed five characteristics of evolution: adaptation, variation, inheritance, domestication, and extinction. These aspects were chosen because they have been found to be imperative to the understanding of biological evolution and to underlie the cognitive bias of essentialism, which is manifested in many alternative conceptions (Heddy & Sinatra, 2013; Shtulman, 2006; Shtulman & Calabi, 2012). All of these aspects were addressed in class. The concepts of adaptation and variation were addressed as part of the TTES model intervention, the concepts of domestication and extinction were taught as part of the control instruction, and the inheritance concept was not dealt with directly as part of the intervention but was inferred during teaching. In the original framework, speciation was also an indicative characteristic (Shtulman, 2006). However, since descent was not a part of the ecology curriculum, and therefore was not taught, we did not include it as a perception board category.

The perception board was photographed with each entry, and the individual visual representation was converted to numerical data. An entry which was in line with the scientific perspective of evolution, i.e., the variational view, was assigned a value of 5, whereas an entry which was fully inconsistent with the scientific perspective of evolution, i.e., the transformational view, was assigned a value of 1. Since the students could position their responses on any of the five scale segments on the board, the numerical value varied between 1 and 5 for each evolution characteristic. Each numerical value was assigned to a student and to a specific date. The analysis included variable frequency calculations (repeated measures analysis of variance [ANOVA]), mean comparisons between the delayed post and the last entry on the board (referred to as post) using the Wilcoxon signed-rank test to ascertain significance, and Duncan's multiple range test was used to assess whether the delayed post entry preserved the gained conceptual change. Visual representation of the individual conceptual change process was created for qualitative assessment of individual and combined conceptual change patterns, and a linear trend line indicating the trend in conceptual change was produced for each student's concepts as well.

3.3.3 Written active use (AU) as indication of transformation

Since one of our research goals was to examine the influence of the TTES model on the students' alternative conceptions regarding evolution, evidence indicative of a transformative process had to be provided. In previous research, the whole transformative process was evaluated using a transformative experience survey. In this survey, the students self-proclaim their motivated use of evolution concepts (AU), indicate the experiential value (EV) that they assign to these concepts, and self-declare their expansion of perception (EP) (Heddy & Sinatra, 2013; Pugh et al., 2010). However, based on our experience, explicitly presenting and referring to the TTES model building blocks in parallel with learning evolution theory may create a cognitive load that will weigh heavily on the learning process, undermining its success and thus influencing the results. Hence, we chose not to divulge the underlying teaching model to the students. Instead, we relied on indirect evidence of a transformative process. Since a student's EV is subjective, we ruled it out as a measure of the transformative process. We also ruled out EP as a measure of transformation to avoid the circular process in which the EP due to conceptual change is both an outcome of the transformative process and a measure of it. That left the students' AU, i.e., the self-initiated use of new learned concepts, as the sole indicator of a transformative process. Our assumption was that the use of a new concept or process with no explicit request or directive to do so is evidence of learning. We therefore hypothesized that AU of new concepts is a fundamental building block in the transformative process that may, in and of itself, testify to the existence of that process, and thus imply expansion of the student's perception. Also, to a certain extent, AU itself is evidence of the value found by the students in using the concept or process. Although AU of a new learned concept or process as a sole measure of transformation might be considered limited and cannot offer information on the magnitude or quality of the transformative process, it is sufficient to indicate the existence of that process.

The strength of AU of new concepts or processes as an indication for transformation increases with its independence. Therefore, it was important to use it while examining products that were not derived from the intervention lessons. As part of the biology matriculation examination in the study country, students are required to submit a written assignment describing a research project. The research unit is learned separately from the ecology unit, with a strong emphasis on research skills. As part of the research project, students participate in a field trip during which they are supposed to recognize biological phenomena and environmental adaptations that might be the basis for their research. The fieldtrip reports handed in by the students in the research group were analyzed for evolutionary terms and explanations. The field trip took place 2 weeks after the intervention had ended and was led by a scientist who did not belong to the school staff. The report was submitted 3 weeks after the intervention ended. The instructions for the environmental fieldtrip report deliberately excluded any specific directive to refer to evolutionary processes, as well as the terms ‘evolution’ and ‘fitness’. The directive was to state an adaptation for the habitat, and its biological *advantage* for *the organism*. This biological advantage was mentioned in the fieldtrip report instructions specifically at the individual level, so if a leap in thinking was made to the population level, it would be done independently. In addition, neither the term ‘evolutionary advantage’ nor the term ‘fitness’ was mentioned. Instead, the vague phrase ‘biological advantage’ was deliberately used, with the option to offer only a biological explanation, rooted in the organism’s biology alone (see Appendix C for the complete environmental fieldtrip report instructions).

A report reference was considered indicative of a transformative process if it included a learned connection to the theory of evolution. As part of the intervention, the evolutionary mechanism was taught with special emphasis on adaptation, the creation of adaptation, and variation. Since the directive for the fieldtrip report included the term adaptation, we excluded it as an indication of AU. Instead, we considered a reference to be indicative of AU if: (i) it included the terms *fitness* or *evolution,* (ii) it related to fitness or to offspring, reproduction, or survivability, (iii) it related to the evolutionary mechanism or to natural selection, variation, or contained a reference to the population level. References including a description of an adaptation and/or an explanation of the advantage of the adaptation for the individual organism were not considered as AU. For example, the statement: “This feature is an advantage for the organism in that the birds with this feature are effectively fed,” was not considered AU, because it neither included the terms fitness or evolution, nor mentioned offspring or a reference to the population level. On the other hand, the statement: “In the past, there were plants whose seeds were stickier, thus more seeds stuck to a bird that came to drink nectar, and there were also plants whose seeds were less sticky so that they stuck less to the birds’ beak. After a few generations, more of the sticky-seeded plants survived, because stickier seeds stuck more than seeds with low stickiness, and so more of the plants with the stickiest seeds reproduced,” was considered AU, because it related to a population of plants, indicated the connection between a trait, reproduction, and survival, and portrayed an evolutionary mechanism.

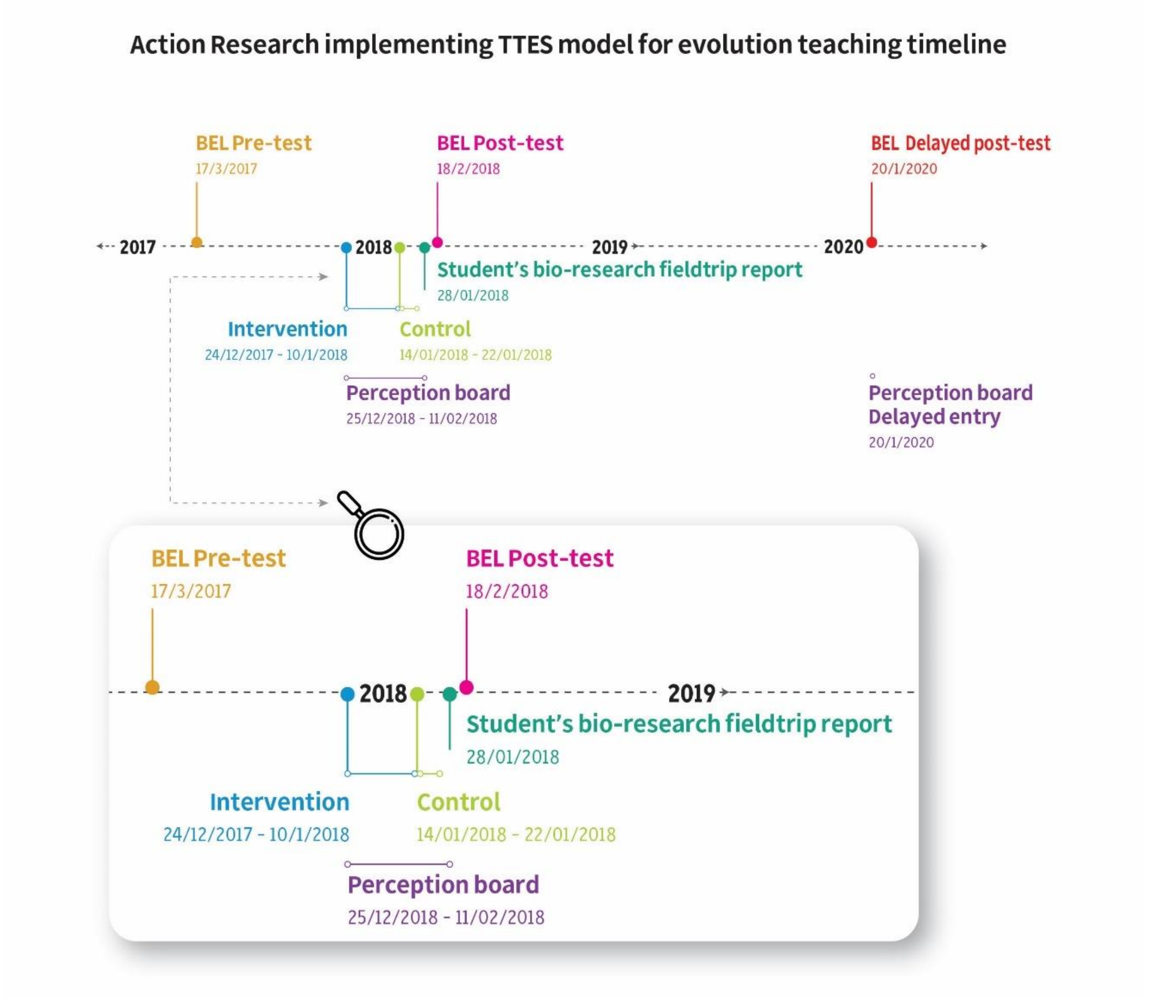


FIGURE 1 Research timeline

3.3.4 Teaching method

The teaching methods implemented in this study for fostering the TTES model principles EV, EP, and AU (Pugh & Girod, 2007) relied heavily on those used in previous research (Pugh, Bergstrom, Heddy, et al., 2017; Pugh & Girod, 2007; Pugh et al., 2010), namely, framing content as ideas, scaffolding re-seeing, and modeling transformative experiences. Other methods that we used, such as supporting AU and reflecting the EV found by students, were derived from the former methods and from our teaching experience. In teaching the intervention, we merged two different classroom strategies derived from the TTES model principles and method: one was part of previous research conducted in a K–12 setting focusing on high-school students, that expressed the model principles via student–teacher interactions during different classroom learning activities, such as the moth lab demonstration or a variation lab, followed by discussions (Pugh et al., 2010); the other used a lecture accompanied by a presentation, an explicit request to "re-see" and use the learned concepts in undergraduate students' everyday lives, and to be prepared to discuss the experience in class (Heddy & Sinatra, 2013). We deviated from these combined plans only by not presenting the model building blocks explicitly to the students because, as already noted, we felt that learning the subject of evolution for the first time and the model simultaneously would create a cognitive load that would undermine the success of the learning process.

It is important to note that both treatment and control lessons were taught sequentially to the same group of participants, by the same teacher. They differed in the teaching method and in dealing with different subtopics of the same subject (Table 1a vs. 1b). The concepts taught in the treatment lesson were adaptation, variation, and natural selection. The concepts taught in the control lesson were domestication and extinction.

Table 4 presents the different ways in which the TTES principles were implemented in the treatment group. It portrays the classroom strategies that were chosen to express the different methods, with a few examples.

3.3.4.1 Treatment

TABLE 4 TTES model implementation design to promote transformation

Implementation method	Classroom strategies	Example	Model principle
Modeling – sharing instructor's experiential value and transformative experiences	Presentations include pictures and narration of teacher's personal. Class practice is laced with stories of the teacher's experiences and their personal value.	Presentation of a picture of *Cinnyris osea* visiting the teacher's living room window for the water dripping on it, accompanied by the teacher sharing the enjoyment in being able to "read its species story" and gaining a sense of belonging to the world in that reminder of all life's mutual story.	EV
Practice in the student's personal life	Homework as an opportunity for students to tether perceptions to their life experiences and to	The students are sent out to perform an observation: to locate and observe adaptations in organisms near their residence, or are	EV

	value the influence of the perception expansion on their lives.	asked to look around them while wondering about evolution as nature’s secret, and to gather evidence and examples for class discussions.	
Reflecting – the experiential value recognized by the students is reflected back to them by the teacher	Promoting metacognitive awareness of the process of assigning value to the impact of broadened perception on personal experiences.	A class example: “It sounds like you really enjoyed looking at…with fresh eyes” or “It’s great to hear that your thoughts of evolution made your hike more interesting. It seems that re-seeing the world this way enriches your life.”	EV
Identifying objects and opportunities suitable for re-seeing practice	Creating classwork relevant to the student’s everyday life. Using experiences in the student’s life as objects for	For a student who lives in the desert, and has nature in her or his backyard, a local Arabian babbler (*Turdoides squamiceps*) is a suitable and available object for re-seeing	EP

	examination through the content lens.	practice; however, the Arabian babbler is not part of everyday life for students living in an urban environment. This student might benefit more from practicing re-seeing with the southern white-breasted hedgehog (*Erinaceus concolor*) on an evening stroll with friends.	
Scaffolding re-seeing	Using infrastructures while learning to re-see. Breaking down the whole process of re-seeing into stages and using each stage as a step to the next one.	<u>Large-scale scaffolding within the unit:</u> Breaking down the whole process of re-seeing into stages: observing an organism, identifying traits, recognizing the connection between traits and the environment, understanding the mechanism of selection, incorporating variation as	EP

	Assisting re-seeing by modeling using the infrastructure to re-see, practicing re-seeing using the infrastructure with the teacher, and repeating the use of the same infrastructure to re-see without the teacher's assistance.	input and adaptation as output. Re-seeing the individual as a member of a species that points to that species' possible evolutionary process. <u>Small-scale scaffolding within lessons:</u> Writing the student's views in the teacher's presentation before, during and after conducting a class experiment simulating selection by using tweezers as beaks, to hunt for paper moths laid on a dark/light bark picture and learning from the statistical outcome. Throughout, the teacher contributes to the reasoning process and	

		discusses it with the students. Students then repeat the experiment and the reasoning process on their own, using a digital simulation of a moth-hunting bird followed by statistical analysis, at home.	
Recognizing the utility of the expanded perception of evolution	Promoting metacognitive awareness of the value of using the broadened perception.	A class example: “It seems that it’s easier for you now to explain that phenomenon to yourself…to theorize why…” (Now: after you have broadened your perception about…, with your new worldview).	EP + EV
Frame content as ideas – creating a classroom culture of idea sharing	Deliberately accepting the student’s opinions as legitimate without judgment of their	A class example: “I’m not giving you the answer. Let’s stay there for	AU

	accuracy, but rather as a basis for scientific inquiry in accordance with the nature of science.	a minute. Pause. Reflect for a moment." "What does that mean? Please explain." "Interesting. What do you think about Student 7's idea?" or "How can we validate this theory?" "Let's write all the ideas on the board."	
	Allowing and legitimizing concept evolution as part of the learning practices.	"Many smart people had a lot of ideas regarding this exact question/what is your idea?" Asking students to place their names on a board between two poles of opposite perceptions (i.e., perception board) at the end of every lesson to indicate their current worldview.	

Supporting active use of terms and ideas	Allowing and encouraging sharing of terms and ideas with the distinct goal of creating a sharing atmosphere.	A class example: “It’s lovely that you have brought to class the concept of…” Deliberate dedication of class time for students to share ideas, examples, theories and experiences.	AU

3.3.4.2 Control

The control lesson was taught classically. The content knowledge was brought to class in the form of a lecture based on facts and examples (content stated in Table 1b). The teacher deliberately did not engage in the implementation methods of the treatment. The teacher’s personal experiences were not shared, examples were general and did not relate specifically to the students’ everyday environment, and awareness of the benefit of new understandings was not prompted. Scaffolding was not planned ahead. However, elements of scaffolding, such as breaking down processes into their elements and going through them step by step, were present during the question and answer sessions following the lectures. Sharing terms and ideas was allowed during discussions but as opposed to the treatment lesson, were judged according to their accuracy and corrected, thus emphasizing content and refraining from framing content as ideas. During the time dedicated to teaching the concepts of domestication and extinction, the overall positive professional relationship with the students was maintained.

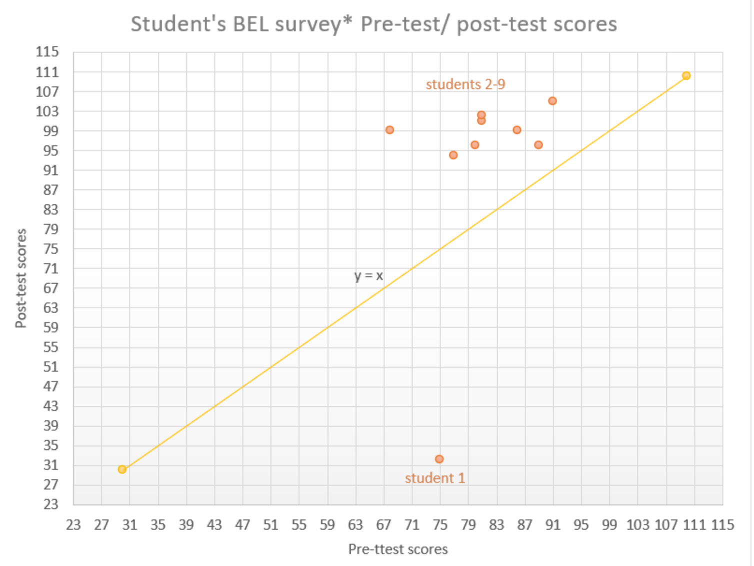
3.3.5 Analyses software

All data descriptive statistics, and advanced statistical analyses were conducted using SAS 9.1 software.

4 RESULTS

4.1 Data screening

The participants were treated as a homogeneous group. Due to the small sampling size, we did not explore demographic or personal group differences. As already noted, student 1's BEL survey results were different from those of the other students (Figure 2a and b).



* Yates, T. B., & Marek, E. A. (2015). A Study Identifying Biological Evolution-Related Misconceptions Held by Pre-biology High School Students. *Creative Education, 6*, 811- 834.

FIGURE 2a Students' BEL survey pre-test/post-test scores

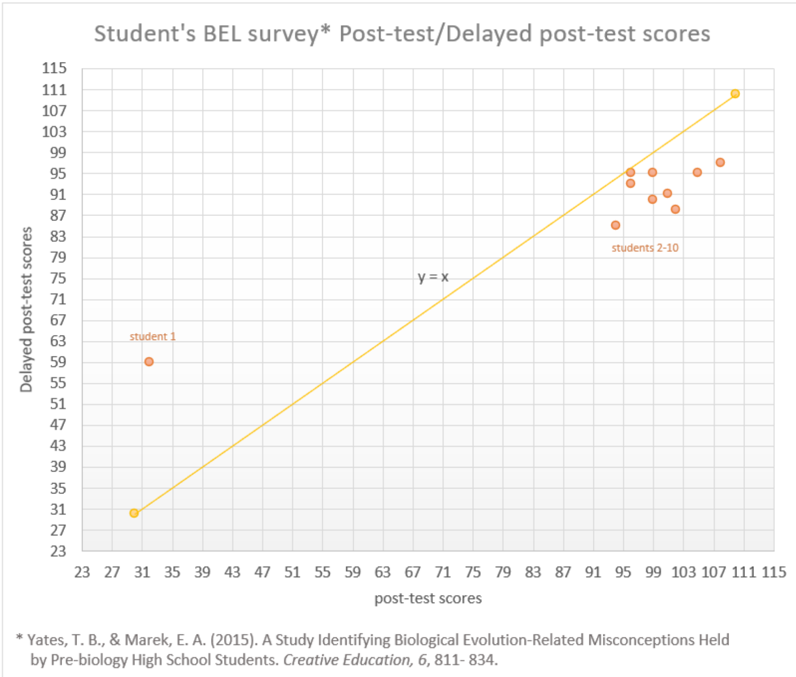


FIGURE 2b Students' BEL survey post-test/delayed post-test scores

Student 1's questionnaire results demonstrated a major drop in achievements after the intervention (post-test), and an increase in the delayed post-test, contrasting with all other students' results. Interviews conducted with student 1 after answering the pre-test, as well as the student's verbal utterances in class from the lesson transcripts, present a picture of knowledge understanding that is not correctly manifested due to difficulties in understanding the test questions.

4.2 Transformative experience findings

To address the first research question: *Are there indications of a transformative learning process following TTES instruction on concepts of evolution in the participant's unrelated submitted assignments?*, we screened the students' fieldtrip reports for evolutionary references indicative of AU. Every report included at least one reference to evolution. The references varied from using the word evolution and/or the term fitness, through referring to the connection between an adaptation and an advantage in bringing offspring and keeping them alive (using the meaning of the term fitness rather than the term itself), to possible references to coevolution discussed in the intervention class lessons. Examples of the references are presented in Table 5.

TABLE 5 Evidence of active use (AU): examples of references to evolution in the fieldtrip reports

Analysis	Evolution references
References to reproduction Different references to the mechanism (reproduction) in which the adaptation prevailed.	*Zilla spinosa* – "The observed adaptation is thorns on the plant. This adaptation helps prevent animals from eating the plant because the long thorns keep the animals away from the plant. This adaptation is an advantage in that *Zilla spinosa* is eaten less than other plants and thus its reproduction is undisturbed."
Mechanistic reference at the population level	Biological explanation – "We're hypothesizing that the seeds of the *Loranthus*

In this reference, we see a clear connection between the *Loranthus acaciae* seed feature to its population's reproduction in a mechanistic explanation that the students were not asked to present. The reference is to the mechanism leading to high abundance of the trait as well as to population variation as a prerequisite for the process, and to the trait increasing fitness.	*acaciae* are very sticky. In the past, there were plants whose seeds were stickier and thus more seeds stuck to a bird that came to drink nectar, and there were also plants whose seeds were less sticky so that they stuck less to the birds' beaks. After a few generations, more of the sticky-seeded plants survived, because stickier seeds stuck more than less sticky seeds, and so more of the plants with the stickiest seeds reproduced."
References to fitness References to offspring imply to fitness. A reference connecting the trait to next generations and to fitness, but with no completion of the idea or reference to the population level.	Adaptation – "The *Buteo rufinus*'s eyes are on the side of its head. It has binocular vision that allows it to analyze a large space [physiological]. The feature gives it an advantage: because of its better vision, it will catch more prey and be able to beget offspring." "The *Blepharis attenuata* has a 'rain watch'. The rain watch is a method developed by desert plants to prevent a situation in which the seeds will not grow and there will be no continuity. The seed has a hard shell, and

Correct and proactive use of the term fitness. Our impression is that the explanation was clearly not describing the evolutionary mechanism. Nevertheless, the use of the term fitness could point to a transformation in a process of maturation.	once the plant 'picks up' a flood, or more correctly the water presses on the *Blepharis attenuata*, the seed comes out of the fruit and can grow on its own because there is water in the soil [physiological]. This feature gives the plant an advantage. With the rain watch, fewer offspring will die from lack of water." Regarding *Loranthus acaciae* – "Once the birds see the red color of the flowers, they know that the flower should not be pollinated and that it has no nectar. The biological advantage of changing the color of the flowers is that this prevents them from being pollinated twice, resulting in unnecessary work, rather than pollinating only flowers that were not pollinated yet. That raises the plant's fitness."
General evolution references An unsolicited reference to the evolutionary process as a concept. The context is the evolution of a trait that	*Blepharis attenuata* – "Rain watch, hard shell of seeds, once there's a lot of water it swells and explodes. This plant, found in dry habitats, is a good example of a number of

enables existence under stressful situations (such as dry habitat).	mechanisms that enable the existence of life in situations of stress, which evolved due to evolutionary processes.”
A reference to evolution, and the comparison of populations, but there is no continuation of the idea as a connection to fitness or completion of the mechanism.	“During the fieldtrip, we saw a phenomenon in which animals like the *Merops apiaster* or scorpions live in underground burrows. This phenomenon is a behavioral adaptation of these animals, which gives them an evolutionary advantage over animals that live outside, because in the burrow, the conditions are relatively comfortable and relatively stable compared to the conditions outdoors. While the other organisms are forced to deal with the changing conditions outside, burrow animals have more consistent and comfortable conditions.”
Class example reference This may be a reference to the intervention's opening lesson, which turned attention to the coevolution of the *Cinnyris osea* and the shape of the flowers it pollinates. Apart from this	“The *Loranthus acaciae* has thin red flowers which advertise the plant to birds and insects for pollination. In addition, the flower’s shape is adapted to the elongated and curved beak of *Cinnyris osea*, which is one of the main pollinators of the flower. During the

reference, there were no evolutionary references in the report.	fieldtrip, we observed *Loranthus acaciae* with little bloom and fruitless.”

Every report included at least one spontaneous reference to evolution. In all 5 reports, there were 12 mentions of evolution. Some of the mentions included the terms *fitness*, *evolutionary process*, *evolutionary advantage*; some described processes such as coevolution and fitness without using the actual terms; and others provided a complete mechanistic evolutionary process spontaneously. The use of terms or processes learned during the intervention in a report written at home, 2.5 weeks after the intervention ended, and as part of another learning unit’s requirements, with no instruction to do so, fulfills the AU criterion and is indicative of a transformative learning process following TTES instruction of evolution concepts.

4.3 Conceptual change and short-term knowledge retention

To address the second research question, *Does TTES instruction result in conceptual change toward the scientifically accepted conceptual model of biological evolution?*, we compared the average percentage of students choosing concepts in accordance with the scientifically accepted model of evolution in the BEL survey (either agreeing with a scientifically accepted statement or disagreeing with an alternative conception statement) between the pre-test and the post-test in different subcategories of the test (Appendix A).

TABLE 6 Evidence of conceptual change in the BEL survey: the percentage of students choosing scientifically accepted concepts of evolution following TTES instruction. (Numbers in parentheses indicate number of statements in category)

Evidence supporting evolution (4)		Mechanisms of evolution (5)		Nature of evolution (4)		Intentionality of evolution (5)		Science, scientific methodology, and terminology (5)	
Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
56%	82%	55%	90%	35%	69%	70%	80%	68%	95%

Table 6 presents the improvement in the percentage of students choosing concepts in accordance with the scientifically accepted model of evolution following TTES instruction in all subcategories of the tests. The intervention did not focus on the subject of intentionality of evolution, which was dealt with only conjunctionally. Thus, the mild improvement in this category suggests a less extreme improvement in the other categories, and strengthens the assertion that the TTES instruction was indeed responsible for a large part of the conceptual change.

We further calculated questionnaire mean per question, and delta of means of the BEL survey results. To ascertain significance of the assertions of meaningful distances between mean test results, we conducted a Wilcoxon signed-rank test.

TABLE 7 BEL survey score assessments – descriptive statistics

Variable	n	Mean	Std dev	*p* value
Pre-test	8	3.563	0.317	
Post-test	8	4.304	0.158	
Del_post-test	8	3.978	0.161	
δ post-test_pre-test	8	0.745	0.303	$\leq$ 0.0039
δ del_post-test_pre-test	8	0.418	0.329	$\leq$ 0.0039
δ del_post-test_post-test	8	-0.326	0.190	$\leq$ 0.0039

Del – delayed.

Table 7 lists the descriptive statistics for the BEL survey score assessments. Performance on the pre-test was low, as expected, because the students had not undergone any formal learning process regarding evolution. The post-test results were significantly higher than the pre-test results, demonstrating conceptual change toward the scientifically accepted model regarding biological evolution.

Since the BEL survey post-test was conducted about 5 weeks after the intervention, the results suggest conceptual change retention, and answer our third research question, *Is the conceptual change in evolution understanding following TTES model implementation preserved over time, demonstrating knowledge retention?* in the affirmative.

Referring to the BEL survey post-test standard deviation as a measure of knowledge-retention dispersal among students, conceptual convergence is demonstrated, thus addressing our fifth question, *Are there any differences in retention among students?* with evidence of minor differences. The BEL survey pre-test's standard deviation was higher than that of the post-test, reflecting the difference between the students' individual pre-teaching knowledge.

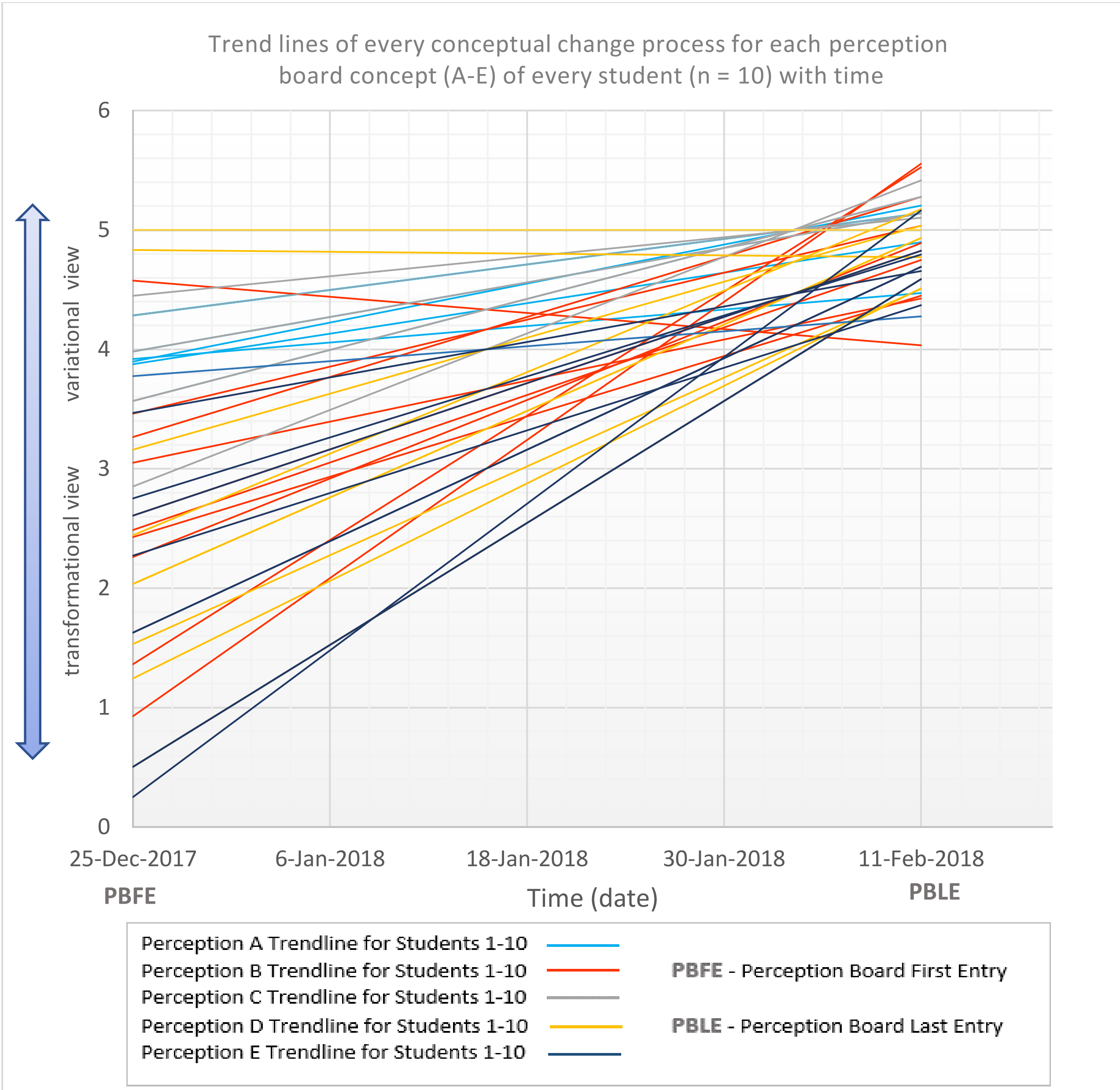


FIGURE 3 Perception boards' conceptual change trend lines for all students' (n = 10) conceptions with time. The different perception board concepts (A–E, Table 3) are represented by five line colors, while different lines of the same color represent the trends of the students' conceptual change process regarding the specific concept

To further substantiate the conceptual change, we examined a visual representation of the perception boards of the students' concept of evolution over time (trend lines in Figure 3). At the beginning of the teaching process, the students' perceptions of the various concepts (concepts A–E, Table 3) were varied, as demonstrated by the divergence of entry points for any specific concept for different students. A general convergence of all perceptions for all students toward the accepted conceptual model is clear. Therefore, a conceptual change toward the scientifically accepted conceptual model regarding biological evolution, i.e., a variational view of the board's concepts following evolution learning, is apparent. This general tendency does not seem to differ between concepts taught using TTES instruction (concepts A and C, Table 3), concepts taught classically (concepts D and E, Table 3), and a concept that was learned conjunctionally and was not taught directly (concept B, Table 3).

An individual examination of the data shows that this pattern is consistent even in cases showing a seemingly opposite trend. In these latter cases, the end entry received the value of 5, thus presenting a perception in accordance with the scientific model, but since the entries before the last entry had lower values, the overall trend moved away from the accepted conceptual model.

Since the perception board's last entry (delayed entry not included) was conducted a month after the intervention and about 3 weeks after the control, its convergence around the score of 5 for all 10 students, representing perceptions completely in line with the scientific model of evolution, answers our third research question: *Is the conceptual change in evolution understanding following TTES model implementation preserved over time, demonstrating knowledge retention?* in the affirmative. However, it is important to note that it demonstrates short-term retention not only for concepts taught according to the TTES model instruction (concepts A and C, Table 3), but also for concepts learned classically (concepts D and E, Table 3), and for a concept that was not taught directly, but was learned conjunctionally (concept B, Table 3).

4.4 Long-term knowledge retention

Table 7 shows a minor decrease to 92% (4%) of the BEL survey delayed post-test mean per question results compared to the post-test mean results. This decrease is expected given the 2 years that passed since instruction. However, it is clear that the delta between the delayed post-test mean results and the pre-test is larger than the delta between the delayed post-test mean results and the post-test (Table 7), demonstrating preservation of the conceptual change.

The delayed entries on the perception board showed a similar decrease (Table 8). However, despite this observed and expected decrease, the students retained the perceptions that they gained while learning using the TTES model 2 years earlier. Wilcoxon signed-rank test demonstrated no significant change between the delayed entries and the last entries on the perception board for concepts A and C, which were taught according to the model, and a significant change in retention between delayed entries and the last entries for concepts B, D and E, which were not learned using the TTES model. This affirmed the connection between teaching using the TTES model and knowledge retention over time.

TABLE 8 Delta of means between perception board delayed entries and perception board last entries and significance according to Wilcoxon signed-rank test

Perception	n	Mean	SD	*p* value
A	10	-0.40	0.70	0.125
B	10	-2.40	1.65	0.0039
C	10	-0.30	0.48	0.125
D	10	-1.20	1.48	0.03125
E	10	-1.10	1.37	0.01565

A univariate ANOVA on the perception board's average scores discerned the outcomes of the different entries per perception. Time was related to as a categorical variable and received seven values according to the perception board entry time (25 Dec 2017, 27 Dec 2017, 01 Jan 2018, 22 Jan 2018, 07 Feb 2018, 11 Feb 2018, 20 Jan 2020. Duncan's multiple range test indicated that the last perception board entry's mean for both perception A (Table 3) dealing with variation, and perception C (Table 3) dealing with adaptation, which were taught using the TTES model, was a part of entry groups (*A*) that were leaning toward the scientifically accepted conceptual model regarding biological evolution. On the other hand, for perceptions B, D and E (Table 3), which were not learned using the TTES model, the test indicated that the last perception board entry's mean was a part of entry groups (*B*) that were leaning away from the scientifically accepted conceptual model regarding biological evolution.

TABLE 9 Univariate ANOVA of the perception board's average scores for different entry dates per perception with Duncan's test for group values

Perception	Phenomenon	F for	F	*p* value	Group
A	Variation	repeated measures model	F(15,50) = 4.40	<0.0001	*A*
		time factor	F(6,50) = 6.38	<0.0001	
B	Inheritance	repeated measures model	F(15,50) = 4.44	<0.0001	*B*
		time factor	F(6,50) = 8.43	<0.0001	
C	Adaptation	repeated measures model	F(15,50) = 5.15	<0.0001	*A*
		time factor	F(6,50) = 8.63	<0.0001	
D	Domestication	repeated measures model	F(15,50) = 5.79	<0.0001	*B*
		time factor	F(6,50) = 7.51	<0.0001	
E	Extinction	repeated measures model	F(15,50) = 10.54	<0.0001	*B*
		time factor	F(6,50) = 21.26	<0.0001	

When examining the perception board results presented in Figure 3, it is clear that there is short-term retention of knowledge for both concepts taught according to the TTES model instruction (concepts A and C, Table 3) and concepts taught classically or learned conjunctionally (concepts B, D and E, Table 3), because trend lines for both present perceptions in line with scientifically accepted concepts regarding biological evolution 3 to 4 weeks after instruction. This picture changes when inspecting long-term retention, as presented in Tables 8 and 9. Looking through the prism of time, there seems to be a significant difference in retention between concepts that were taught according to the TTES model (concepts A and C, Table 3), which did not show a significant mean difference from scientifically accepted concepts regarding biological evolution, and concepts which were taught classically or learned conjunctionally (concepts B, D and E, Table 3) and presented a significant mean difference from scientifically accepted concepts regarding biological evolution. This observation, also presented visually in Figure 4, answers our fourth research question, *Is there a difference in short- and long-term retention of concepts learned using the TTES instruction and concepts learned using traditional teaching methods?* in the negative for short-term retention, and affirmative for long-term retention.

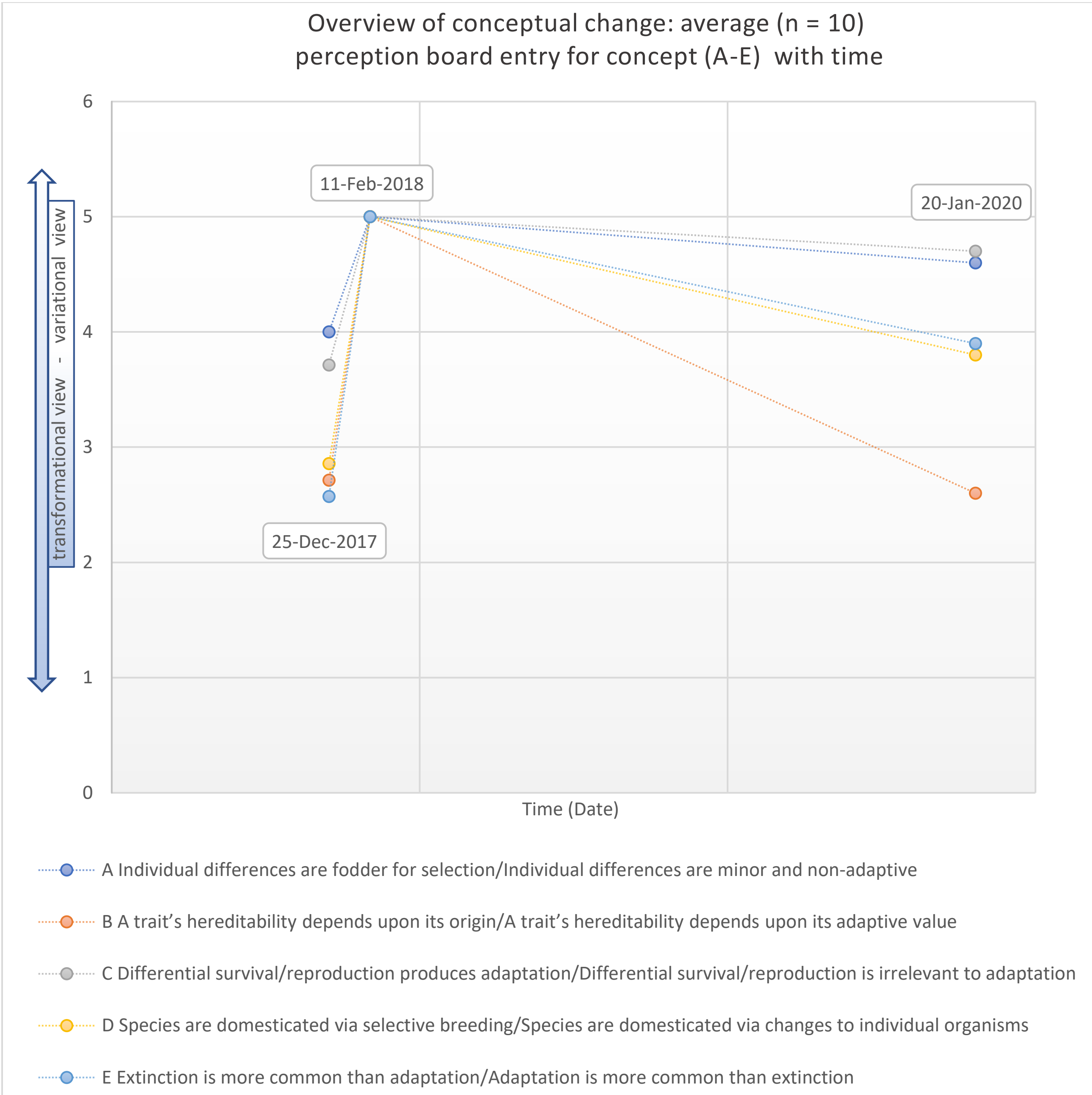


FIGURE 4 An overview of conceptual change: average (n = 10) perception board entry for concept (A–E) for three points in time: first and last entry, and delayed entry

As for our fifth research question, *Is there a difference in retention among students?*, the results of the BEL survey (Table 7) show that the differences in knowledge retention between students, in both the short term and long term, are minor, because the standard deviations from the average of the BEL survey post-test (0.158) and delayed post-test (0.161) are twice as low as the standard deviation of the BEL survey pre-test (0.317). Looking at the perception board descriptive statistics of the gap between delayed entry compared to last entry of the perception board (Table 8), the standard deviations of perceptions A and C (0.70, 0.48) are two to three times lower than those of perceptions B, D and E (1.65, 1.48, 1.37), indicating that knowledge preservation of perceptions learned using the TTES model is characterized by small differences between students compared to otherwise studied concepts.

5 DISCUSSION

Results showed that following the TTES instruction, a transformative process took place. Every fieldtrip report written by the students for their research project included some degree of evidence of AU. The students were engaging with the learned evolution concepts outside of class, and used evolution terms, concepts or mechanisms in their reports with no explicit request or directive to do so. The students thus exhibited the broadened worldview they had acquired, and the AU itself inferred the value that the students found in using that worldview. Both EP to include out-of-school experiences, and acknowledgement of the worldview's EV are building blocks of a transformative process (Pugh, 2011; Pugh, Bergstrom, Heddy, et al., 2017; Pugh & Girod, 2007; Pugh et al., 2010), and thus testify to its existence and influence.

In addition, TTES was very effective at facilitating conceptual change with respect to evolution ideas. Results demonstrated improvement in the percentage of students choosing concepts that align with the scientifically accepted model of evolution following TTES instruction. These data reaffirm previous assertions of the effectiveness of the TTES method in promoting conceptual change regarding evolution ideas (Heddy & Sinatra, 2013).

The main purpose of this study was to assess whether teaching using the TTES model would affect retention of knowledge of evolution for the short and long term. The passage of time after learning events is known to negatively influence knowledge retention. An obliterative stage of assimilation takes place progressively after learning, and leads to a growing inability to retrieve the newly learned ideas (Ausubel, 2000). We found the BEL survey results especially interesting, because they demonstrated significant knowledge retention over time, in both the short term and long term, after instruction, with a high percentage of preservation of the acquired knowledge of evolution after 2 years.

The acquired knowledge in evolution was not formally learned or rehearsed during the period from the end of the intervention to the administration of the BEL survey post-test. Since the meaning of new ideas as separate entities tends to be forgotten over time if not rehearsed or overlearned (Ausubel, 2000), it stands to reason, given the results, that the students performed an informal rehearsal of evolutionary ideas during that time interval. This assumption is supported by the AU of evolutionary ideas by the students, as manifested in the analysis of their fieldtrip reports. The TTES quality of AU, in and of itself, testifies to the self-initiated retrieval of ideas about evolution by the students. Since repeated retrieval practice is known to enhance long-term retention (Karpicke & Roediger, 2008; Roediger III & Butler, 2011), we suggest the possibility of recurrent self-initiated retrieval (AU) as the key component in the mechanism by which the TTES model enhances short-term and long-term retention.

The perception board results confirmed the trend of conceptual change toward the scientifically accepted model of evolution presented by the BEL survey results. Moreover, since the perception board results also refer to students' perceptions regarding concepts in evolution that were not taught using the TTES model, its use provides an opportunity for an internal comparison between the retention of perceptions regarding these different concepts: the board's last entry, made a month after the end of the intervention, and 3 weeks after the end of the control intervention, showed no difference between concepts taught using the TTES model and the control. All of the results were aligned with the scientifically accepted model, demonstrating retention of conceptual change that is not necessarily exclusive to the TTES instruction. However, in the delayed board's entries, we found a significant difference between perceptions of concepts taught using the TTES model, and perceptions of concepts taught classically. The students retained the scientific view of the perceptions of concepts taught using the TTES model, which were not significantly different from the board's last entry perceptions. In contrast, the students did not retain the scientific view of the perceptions of concepts taught classically that characterized them 2 years prior.

The TTES model instruction cannot be claimed to be the sole factor responsible for the delayed board's entries, due to the extended period of time that passed between the intervention and the measure. However, a long-term influence can be suggested. The proposed mechanism is that of self-initiated recurrent retrieval, or AU. The TTES model promotes acknowledgment of the EV of the learned concepts of evolution to the students' everyday lives. In addition, as part of the TTES model implementation, the students are asked to practice their new evolutionary worldview in their personal life environment. Given that a transformation did occur, the TTES-taught evolutionary concepts were perceived as important or substantive to the students' new worldview, and their retrieval was therefore self-initiated, i.e., actively used during the long-time interval. Since, as already noted, repeated retrieval practice is known to enhance long-term retention (Karpicke & Roediger, 2008; Roediger III & Butler, 2011), and since reactivating a memory, or even a component of that memory, may strengthen it (MacLeod, Reynolds, & Lehmann, 2018), AU might be a key factor encouraging retention.

Moreover, homework assignments during the implementation were deliberately performed in different environments—in the students' daily living environments—to emphasize the value of the learned concepts in the learners' everyday life experiences. Since environmental contexts may serve as retrieval cues for experiences that occurred within those contexts (S. M. Smith, 2013), practicing in the students' immediate environment may have encouraged recurrent self-initiated retrieval over the course of 2 years, thus contributing to the retention of the knowledge in evolution. Another possible explanation for the long-term retention results is that the very use of evolution concepts in different situations links those same concepts to different anchoring ideas and increases their stability, thereby strengthening the memory of them (Ausubel, 2000).

5.1 Limitations

Since this study was conducted as an action research, the first author served as the instructor for the intervention and control lesson, and was therefore not blind to condition. This approach, limited as it may be, has benefits, such as keeping the instruction teaching style consistent, and controlling the content of background knowledge of evolution influencing both the intervention and the control. However, this raises the question of whether the reported results are solely the consequence of an instructor effect: we believe that this is not the case, for several reasons. First, the TTES model was successfully implemented, with similar results regarding transformation and conceptual change, in a previous study in which the instructor was a controlled variable (Pugh et al., 2010). Second, similar results regarding transformation and conceptual change have been presented by other researchers using different research tools and measures (Girod et al., 2010; Heddy & Sinatra, 2013; Pugh et al., 2010). Finally, another study among 5th-grade science students, in which the intervention teacher was the researcher and the control teacher was an experienced teacher, reported less forgetting over time as a consequence of teaching for transformative experience (Girod et al., 2010).

Since both the intervention and the control were taught by the same teacher to the same students consecutively, there are two other variables to consider when attempting to suggest a theory that might explain the results. One is time, and the other is self-initiated retrieval, or AU. One can claim that the perception board’s last entry does not describe retention of knowledge like the BEL survey does, on account of the repetitive nature of the board's use. Taking this into account, we might refer only to the board’s delayed entry results as indicative of retention.

This study was conducted with a small sample of students (n = 10). Despite the significant results, we acknowledge this as a limitation that prevents generalization of our findings. It should be noted that this study displays a phenomenon and as such, sheds light on a potentially promising knowledge-retention outcome of TTES model instruction.

Another limitation stems from the nature of the long-term retention study itself. Considering the time elapsed from instruction, is it impossible to isolate the effects to the particular independent variables involved (Ausubel, 2000). Hence, we cannot infer a direct and exclusive link between the long-term retention results and the TTES instruction in the intervention. Nevertheless, it would be wrong to ignore the results altogether for several reasons. First, extensive influence, even for long periods of time, does not directly negate the existence of the first influence; in other words, the influence of the instruction coexists with later influences, and since the TTES instruction deliberately encouraged the students to assign personal meaning to the learned worldview, this influence may even have been enhanced. Second, the proposed mechanism of self-initiated retrieval for the retention of knowledge in evolution could have strengthened the influence of the learned evolution ideas over time.

5.2 Conclusions and future directions

Our data suggest that use of TTES instruction led to the adoption of a scientific worldview of evolution, and to short- and long-term retention of the acquired knowledge in evolution. Since maintaining a scientific evolutionary worldview is imperative for science literacy, and scientific academic development and research (Alters & Nelson, 2002; Pobiner, 2016), and since our findings represent a desired, but not characteristic outcome of learning evolution (Georghiades, 2000; Nehm & Reilly, 2007), it might be worth further studying the holistic approach to evolution instruction, portrayed in this article by the TTES model, as a possible vehicle for these outcomes. The TTES model instruction that was articulated by Pugh and Girod (2007) in the Deweyan spirit, not only deals with broadening students' perceptions to include out-of-school world experiences (EP); it also takes into account and directly engages and refers to the personal value assigned by the students to new learned concepts (EV), and the students' tendency and motivation to make use of the learned concepts of their own accord, in their everyday experiences (AU).

A few future research directions are suggested: repeating the research with a larger sample to substantiate the results and allow for their generalization; further exploring the possible mechanistic connection between the TTES principles and the observed retention of evolution knowledge, and the role that self-initiated retrieval might play in creating these outcomes; exploring the effectiveness of TTES in facilitating knowledge retention for other science topics which might contribute to creating the students' worldview.

Disclosure statement

No potential conflict of interest is reported by the authors.

APPENDIX A: BIOLOGICAL EVOLUTION LITERACY (BEL) SURVEY

Please indicate how much you agree or disagree with each of the following, according to this scale.

(1) Strongly agree
(2) Somewhat agree
(3) Undecided/Never heard of it
(4) Somewhat disagree
(5) Strongly disagree

No.	Category†	1–5	Statement
1.	SSMT1		A scientific theory that explains a natural phenomenon can be classified as “a best guess” or a “hunch.”
2.	SSMT2		The scientific methods used to determine the age of fossils and the earth are reliable.
3.	SSMT3		Nature aspires to simplicity. Hence, complex life forms cannot evolve from simpler life forms.
4.	SSMT4		The earth is old enough for evolution to have occurred.
5.	SSMT5		Evolution cannot be considered a reliable explanation because evolution is only a theory.
6.	IE1		Evolution always results in improvement.
7.	IE2		Members of a species evolve because of an inner need to evolve.

8.	IE3		Traits acquired during the lifetime of an organism—such as large muscles produced by body building—will not be passed along to offspring.
9.	IE4		If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation.
10.	IE5		Evolution cannot cause an organism's traits to change within its lifetime.
11.	NE1		New traits within a population appear at random.
12.	NE2		Individual organisms adapt to their environments.
13.	NE3		Evolution is a totally random process.
14.	NE4		The environment determines which traits are best suited to survival.
15.	ME1		Variation among individuals within a species is important for evolution to occur.
16.	ME2		"Survival of the fittest" means basically that "only the strong survive."
17.	ME3		The size of the population has no effect on the evolution of a species.
18.	ME4		Complex structures such as the eye could have been formed by evolution.
19.	ME5		Only beneficial traits are passed on from parent to offspring.

20.	ESE1		There exists a large amount of evidence supporting the theory of evolution.
21.	ESE2		According to the theory of evolution, humans evolved from monkeys, gorillas, or apes.
22.	ESE3		Scientific evidence indicates that dinosaurs and humans lived at the same time in the past.
23.	ESE4		Most scientists favor evolution over other explanations for life.

†SSMT, science, scientific methodology, and terminology; IE, intentionality of evolution; NE, nature of evolution; ME, mechanism of evolution; ESE, evidence supporting evolution.

APPENDIX B: THE PERCEPTION BOARD REPRESENTATION

Perception	1	2	3	4	5	Perception
Individual differences are fodder for selection						Individual differences are minor and non-adaptive
A trait's hereditability depends upon its adaptive value						A trait's hereditability depends upon its origin
Differential survival/reproduction is irrelevant to adaptation						Differential survival/reproduction produces adaptation
Species are domesticated via changes to individual organisms						Species are domesticated via selective breeding
Adaptation is more common than extinction						Extinction is more common than adaptation

APPENDIX C: INSTRUCTIONS FOR ENVIRONMENTAL FIELDTRIP REPORT

The relevant text

The complete fieldtrip report instructions included general information, habitat characteristics, measurements, references to organisms and phenomena, and bibliography. Here we include only the directives that allow for the possibility of referring to evolutionary concepts independently.

Describe three adaptations of organisms observed on the fieldtrip. For each match, specify what you consider as adaptation, how the organism benefits from the adaptation, and which subject, among the following, it helps:

In plants or animals:	Explain the organism’s adaptation to its habitat or to the habitat's weather conditions.
Plants:	Preventing the plant from being eaten by animals
	Method of plant pollination
	Seed distribution
Animals:	Protection from predators
	Obtaining food
	Inter- or intraspecies communication

The adaptations may be found in different organisms, or in the same organism.

Describe three biological phenomena observed in the field. Biological phenomena are structures, shapes, processes, or connections that appear in a particular organism rather than in others, or under certain conditions rather than others (e.g., characteristics that are unique to certain details of the same species, to certain cells in the body, different in a particular organism than in the others, or appearing in one place rather than another, at one time rather than another, etc.). At least one of the phenomena must be related to a biological interaction. The phenomenon must differ from the adaptations referred to above. Offer a biological explanation or an explanation of the biological advantage of one of the phenomena.

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