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PESQUISA EMPÍRICA

The Impact of Transformational Learning Theory on Conceptual Change, Engagement, and Critical Thinking in Physics Education

O impacto da teoria da aprendizagem transformacional na mudança conceitual, no engajamento e no pensamento crítico no ensino de física

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Abstract. This study sought to investigate the effects of implementing transformative learning theory on the conceptual growth, learning engagement, and critical thinking of physics students in secondary school. The sample consisted of 62 first-year high school students, divided into two groups: 30 students in the experimental group and 32 in the control group. To achieve the objectives of the study, the Conceptual Change Test (CCT), Critical Thinking Test (CTT), and Engagement in Learning Scale (ELS) were created. The results demonstrated how transformative learning theories influence conceptual transformation, learning engagement, and the growth of critical thinking in physics. the study recommended using of transformative learning theory in the context of physics learning and conducting more studies on the transformative learning theory and its effects on deep understanding, building self-interpretations, and reflective thinking in physics.

Keywords: Conceptual Change, Engagement in Learning, Critical Thinking, Transformative Learning Theory, Physics.

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Resumo. Este estudo buscou investigar os efeitos da implementação da teoria da aprendizagem transformadora no desenvolvimento conceitual, no engajamento com a aprendizagem e no pensamento crítico de estudantes de física do ensino médio. A amostra foi composta por 62 alunos do primeiro ano do ensino médio, divididos em dois grupos: 30 alunos no grupo experimental e 32 no grupo de controle. Para atingir os objetivos do estudo, foram elaborados o Teste de Mudança Conceitual (TMC), o Teste de Pensamento Crítico (TPC) e a Escala de Engajamento na Aprendizagem (EEA). Os resultados demonstraram como as teorias da aprendizagem transformadora influenciam a transformação conceitual, o engajamento com a aprendizagem e o desenvolvimento do pensamento crítico em física. O estudo recomendou o uso da teoria da aprendizagem transformadora no contexto do ensino de física e a realização de mais estudos sobre essa teoria e seus efeitos na compreensão profunda, na construção de autointerpretações e no pensamento reflexivo em física.

Palavras-chave: Mudança conceitual, engajamento na aprendizagem, pensamento crítico, teoria da aprendizagem transformadora, física.

Introduction and Literature Review

Physical concepts and cognitive structure formation

Imanova (2022) defines physics as the study of natural phenomena. Physical knowledge is regarded as a collection of ideas, linkages, generalizations, and laws organized in a network of scientific interactions and connections to give it an ordered structure (Tolba, 2023). Physical concepts are the heart of the cognitive structure of physics and are defined as a set of organized mental inferences that the learner forms from objects or events available in the environment, or abstract mental representations expressed in symbols or words for a group of events that have common characteristics (Shea, 2018). Concepts are packages of meaning

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that are formed in the learner's mind, and they refer to the regularity that occurs in scientific phenomena and the components within them (Novak, 1996).

The concept is a human invention that provides a framework for organizing the world and events that take place within it (Nersessian, 2010). Tolba (2023) and Osta Vélez (2020) agree with this, as they believe that concepts are bundles of meaning that express the consistency that occurs between events, things, and phenomena, and through them, the human experience of the learner.

Physics is characterized by its advanced conceptual structure, and this structure includes a set of physical concepts linked together by logical relationships. Scientific knowledge is formed through a network of scientific concepts that a person forms while trying to understand physical phenomena (Osta Vélez, 2020). The individual's possession of a good conceptual structure represents the basis upon which meaningful learning of new knowledge is based (Novak, 2002).

The impact of the learner's conceptual structure on the learning process is shown by reconstructing new knowledge differently in memory, creating rich and multiple retrieval paths for conceptual knowledge, and facilitating access to knowledge which reduces the overload on working memory, and increasing the richness of the learner's conceptual structure by integrating new concepts within it (Anderson et al., 2000; Blankenstein et al., 2013; van Kesteren et al., 2012).

Distortion of Physical Concepts and Conceptual Change

Physical concepts like Newton's laws of motion, the laws of dynamics, the laws of electricity and magnetism, quantum mechanics, balanced vectors and forces, simple harmonic motion, projectile motion, etc., have been shown in numerous studies to be complex, abstract, and have multiple representations. They are also difficult to learn and teach. The student consequently loses interest in these concepts and forms false impressions since he is unable to accurately acquire a comprehensive understanding of them (Awudi & Danso, 2023; Badruldin & Alias, 2022; Bello et al., 2018; Gurcay & Gulbas, 2017). As a result, they performed worse in physics (Bello et al., 2018; Gurcay & Gulbas, 2017; Seprapti et al., 2023). The formation process is distorted by conceptual difficulties and a lack of understanding of physical notions, which also act as a prelude to misunderstandings or alternative conceptions (Chen & Techawitthayachinda, 2021). These alternative conceptions weaken and deteriorate the learner's cognitive structure and hinder his ability to understand and interpret physical concepts, creating conceptual difficulties that limit his ability to explain scientific phenomena (Seprapti et al., 2023) because they conflict with scientific views.

Over time, alternative concepts become rooted in students' daily experience (Gomez-Zwiep, 2008), receive cognitive support, and are therefore difficult to change (Park & Kim, 1998). Researchers believe that when a learner is presented with a different event or new evidence that contradicts his misconceptions, the learner ignores it; or provides an explanation for it according to his misconceptions or modifies what is known as the "protective belt" without changing the essence of his previous perceptions, and maintaining what is known as the "hard core" of his misconceptions (Jiang et al., 2018).

Because they represent a mental model in the learner's mind that is challenging to replace with correct concepts, alternative concepts — a combination of the student's knowledge and ideas in his cognitive repertoire — can impede learning because they are inconsistent with the correct concepts associated with the learning contents (Kummer et al., 2016). According to Hewson and Hennessy (1992), conceptual transformation is the mental process by which students realize how their concepts fit into their cognitive framework and begin to view learning as an intentional and deliberate process. It is the changing, modification, or rejection of false conceptual beliefs as a result of exposure to a situation that creates a discrepancy between these beliefs and new knowledge (Novak, 2002; Tobin, 1992). According to White and Gunstone (1989), Conceptual change is a change in principle or belief, meaning abandoning an old principle and committing to a new belief about the scientific concept or phenomenon.

According to Posner et al. (1982) and Hewson and Hewson (1984), several basic requirements must be met for conceptual change to occur, the most important of which are the learner's dissatisfaction with misconceptions or alternative conceptions as a path to creating conceptual conflict between correct and incorrect concepts, the state of clarity in which the learner knows the meaning of the concept and its implications, the state of belief in which the learner believes that the scientific concept is correct and consistent with other accepted concepts, and the state of productive production in which the learner becomes able to use correct scientific concepts to solve problems that were previously unsolvable.

Engagement in Learning

The process of conceptual change requires the learner to be engaged in an active learning process, to exert more effort, and to have motivation and positive feelings towards making this change. Engagement is one of the manifestations of the motivating desire to participate in learning activities, and includes common behaviors such as perseverance, independence, focusing on main ideas and goals, and processing information (Elliot et al., 2015).

It also represents the embodied form of motivation and is evidence that the learner in the learning process is about to use intellectual resources and employ various thinking abilities and skills (Fredricks et al., 2004). In addition to engaging in activities related to the learning material and linking it to prior knowledge and the process of asking questions and obtaining explanations that link prior knowledge to new concepts (van Riesen et al., 2019).

Motivation refers to an individual's dispositions, energy, and orientation toward learning and achievement (Collie & Martin, 2019). Academic engagement refers to the thoughts, behaviors, and emotions that reflect this inclination, energy, and motivation (Fredricks et al., 2004; Martin et al., 2017). It is the amount of effort expended by the learner to participate in school activities and form positive attitudes and tendencies toward learning and integration into it, by showing behaviors such as persistence and interest in the learning process (Fuertes et al., 2023; Mai et al., 2023). Thus, engagement can be considered a manifestation of motivation (Martin et al., 2017).

Motivation and engagement strongly express the degree of learner engagement in the classroom, enjoyment of the learning process, educational aspirations, learning and academic achievement, and use of adaptive learning strategies (Ginns et al., 2018). Motivation is a psychological factor that influences the direction, intensity, and continuity of students' behavior in academic environments (Pajares & Valiante, 2002), i.e. it is a motivating factor for learning, and a decisive factor in the learner's engagement in an active learning process, achieving achievement, and accessing high-quality education (Dogan, 2015). Thus, motivation and engagement are considered one construct.

Engagement consists of an internal psychological drive that leads to action, i.e., engagement behaviors (Bandura, 1986), and is a motivation-driven mental construct that predicts a learner's cognitive and emotional desire to engage in learning contexts and activities (Fredricks et al., 2004). Motivation is one of the variables that influence how behavior is mentally prepared and manifested as an action (Engagement) (Slavin, 2021), and therefore the lack of motivation and desire to learn will negatively affect the learner's effort and pursuit of learning, and he will not be able to face learning problems and academic performance will decline and this is shown in the lack of engagement in effective performances (Eccles & Wigfield, 2002).

Fuertes et al. (2023) indicate that there is a relationship between academic motivation, student engagement, and academic performance. The learner who is not engaged in the learning process shows annoying behaviors that hinder the learning process, such as not performing educational activities consistently and not insisting on achieving valuable educational goals (Fredricks et al., 2004).

The research hypothesized that student engagement is a construct consisting of three basic dimensions, such as cognitive engagement, behavioral engagement, and emotional engagement, which can be explained as follows (Vega, 2012):

Cognitive engagement which refers to students' commitment to their learning. It is based on effective and organized learning methods, in addition to self-organization and planning of learning activities. In cognitive engagement, the learner focuses on achieving goals, is flexible in his work, and deals with failure.

Behavioral engagement, which represents students' participation in academic activities using learning strategies that aim to maintain behavioral patterns that make them approach the learning process, attend learning lessons, and cooperate and communicate with peers.

Emotional engagement reflects students' emotional reactions to the learning process and the elements of the educational process. It includes feelings and attitudes of the learning environment that motivate the learner to take the initiative to start the learning activity. It indicates the degree of the learner's integration into the learning process and feeling an emotional bond with the school, teachers, and peers.

Studies have also supported the importance of developing learner engagement in learning through the use of teaching models, self-regulated learning strategies, metacognitive strategies, technological applications, computer simulation programs, activating prior knowledge, providing enjoyable tasks, and using curricular and extracurricular activities (Adegoke, 2012; Dong et al., 2020; Hampden-Thompson & Bennett, 2013; Linnansaari et al., 2015; Pecore et al., 2017; Susan & Eugene, 2011; Yang et al., 2018).

Critical Thinking

Critical thinking is one of the priorities of education in the twenty-first century, one of the requirements of the modern era, and one of the sources of thinking that enhances the learner's ability to adapt humanely and open up to experience, and to bring about a transformation in thinking and perspective on events and ideas (Norris, 1985). Critical thinking is synonymous with good thinking; it is a widespread and autonomous human phenomenon (Facion, 2015). It is the ability that allows the learner to freely express ideas and generate high levels of thinking and experience (Carter, et al., 2017; Deringöl, 2019). It includes higher-order thinking skills such as analysis, which includes Separating the parts of a problem into their basic components and recognizing and distinguishing patterns, synthesis which involves putting parts together to form a new structure, evaluation which is related to constructing and issuing a judgment or decision in light of authentic criteria (Facione, 2015; Page & Mukherjee, 2007).

There is diversity in critical thinking skills. Ennis (1989) believes that they are represented in the skill of clarification, the skill of decision-making, the skill of inference, and the skill of clarification. While Fajari et al. (2020) indicated that there is a relationship between motivation and critical thinking, and that learning motivation has an impact on critical thinking skills, i.e. the more students are motivated and engaged in the learning process, the more their critical thinking skills increase. The literature agrees that critical thinking skills are determined by the skills of analysis, interpretation, evaluation, inference, explanation, and self-regulation (Facione, 2015; Febri et al., 2019; Yang & Chou, 2008).

Zetriuslita et al. (2017) emphasize the importance of critical thinking in enhancing the learner's ability to think about the information and evaluate it carefully before taking action on it, and to develop plans and make an accurate decision to solve their problems. The learner needs to possess critical thinking skills not only to be able to identify and overcome the problems he faces in daily life (Nugraheni et al., 2022) but also to prepare him to compete in the modern world and be open to new ideas (Duffy et al., 2022).

According to Zhao et al. (2016), Critical thinking tends to expand students' learning experience, making content learning deeper and more meaningful. Tolba (2017) also views critical thinking skills as essential tools in a rapidly changing society, that contains many alternatives and options and requires decision-making. It is one of the important human abilities in the process of self-evaluation and transformation in thinking, and represents the basis for science and democracy, and therefore should be a central goal of education (Lau, 2011).

Although the acquisition of critical thinking skills is important, education systems hinder the acquisition process. Existing teaching systems and practices constitute a major obstacle to the acquisition of critical thinking skills (Karahan et al., 2023). According to Osborne (2014), critical thinking can be enhanced in science classrooms by providing sufficient opportunities for the learner to engage in criticism, analysis, constructing arguments, and discussions, and to build a deep understanding of scientific concepts.

Although the acquisition of critical thinking skills is important, education systems hinder the acquisition process. Existing teaching systems and practices constitute a major obstacle to the acquisition of critical thinking skills (Karahan et al., 2023). Many studies have been conducted that emphasize the importance of developing critical thinking skills using different teaching strategies and models (Amin et al., 2020; Aydın Gürler & Kaplan, 2023; Chen & Chuang, 2021; Çetin, 2020; Matanlari et al., 2020).

The Transformative Learning Theory (TLT) in the Context of Physics Learning

Mezirow (2009; 1999) indicates that the transformative learning theory is an educational theory that works to change the educational pattern of the way and manner in which the learner deals with previous experiences and knowledge, and subjecting them to examination and thinking about them consciously and with critical reflection, to make a sound decision about them to transform and change them. Hence, it is a theory for constructing meaning and understanding experience and building interpretations about it, and using these interpretations later to guide the process of making decisions and actions (Hoggan & Hoggan-Kloubert, 2022). It provides an in-depth analysis of how an individual learns, how he creates the learning experience, and how he tests and examines the beliefs, perceptions, and assumptions that he previously held deeply and that are usually guarded by strong defenses that protect them from erosion and disintegration (Billings–Padiachey & Motsisi, 2023; Maiese, 2017).

Transformative learning theory (TLT) supports the vision of the cognitive approach to learning and that it is important to enable the learner to learn how to free himself from inaccurate ways of thinking that hinder him from making sound decisions and working effectively, and he must also construct meaning and adopt new perspectives (Hoggan & Finnegan, 2023). It also supports the vision of the social approach to learning; The learner formulates meaning around new knowledge throughout the learning process, by engaging in group discussion; talking and dialogue with others helps the learner to realize and know the assumptions he has, reveal new experiences and perspectives, and practice reflective and critical thinking, which provides him with opportunities to explore and acquire the knowledge and skills necessary to achieve the transformation process (John, 2016; Kokkos, 2024; Mezirow, 2009).

Transformative learning is an activity that occurs socially to lead to a deep level of understanding, building experiences, and changing and shifting perspectives. In light of this, transformative learning is defined as a type of learning in which a transformation occurs in the individual’s previously held ideas, beliefs, and assumptions, and an examination of previous experience, knowledge, and information that arose through his experiences and the surrounding environment, to reach supporting or rejecting evidence for it (John, 2016; Maiese, 2017). It is a type of learning in which the new experience becomes compatible and consistent with the meaning structures that the individual possesses and then is accepted or internalized, or is contradictory and conflicting with them, causing a problem or dilemma (Buttigieg & Calleja, 2020; Mezirow, 1999; Taylor, 2017). To resolve this contradiction or conflict or solve that problem and dilemma, the individual must practice contemplation and critical thinking between the new experience and the one he previously possessed (the centrality of experience) to decide whether to reject or review it to be compatible with the new experiences. Here, the transformation occurs to assimilate and absorb new experiences (Khupe & Nyamupangedengu, 2024; Mezirow, 1999).

It is also known as a change in the individual's frames of reference (the centrality of experience), including concepts, values, feelings, associations, and meanings about experience and the world. To form a broader perspective for it (John, 2016; Maiese, 2017); it is a gradual transformation process towards reconstructing the perspective of experience or the world; in which the learner practices independent and reflective thinking and tries to review his interpretations of knowledge and the world around him to build more comprehensive conceptual systems and mental models, open to the world and new experience (Mezirow, 2009; Şahin & Ddgantay, 2018). Or a gradual transformation process that occurs as a result of an existing conflict between the frame of reference that the individual possesses "cultural, cognitive and social heritage" and new experiences, in which the individual seeks to resolve this conflict by practicing conscious thinking processes, which with it this framework is revised and modified to be more consistent with new and valid experiences (Dirkx & Mezirow, 2006).

Transformative learning, which is a meaning-building experience, is based on several basic principles: (1) The dilemma or problem, which arises from a contradiction between the learner's frames of reference, known as "the centrality of experience" and the new experiences that are being learned, which leads to a disturbance in those frames of reference (Hatcher, 2004). (2) Reflective thinking, which encourages students to critically examine frames of reference, highlight "the centrality of experience", and contrast them with fresh experiences in order to decide how to adjust and improve their understanding (Martins & Strawer, 2017). (3) Rational discourse is the process by which the learner presents his opinions and views about the frames of reference (assumptions and experiences) along with arguments and supporting details (Mezirow, 1999, 2009). These principles constitute three basic stages of transformative learning.

Transformative learning stages have powerful effects in the context of physics learning. Physics includes a complex body of physical concepts that are meaningfully linked to each other in a way that indicates the interconnectedness and regularity occurring in the universe (Imanova, 2022; Nersessian, 2010). Research has agreed on the difficulty of these concepts, which leads the learner to distort them and form alternative concepts around them (Awudi & Danso, 2023; Badruldin & Alias, 2022; Bello et al., 2018; Gurcay & Gulbas, 2017). Over time, they become rooted in students' daily experience and are known as the centrality of experience (Gomez-Zwiep, 2008), and thus are difficult to change and shift from (Park & Kim, 1998). It becomes important to induce change or Conceptual modification of these frames of reference, creating a conflict between them and new knowledge (Novak, 2002), and seeking to resolve this conflict.

In light of this, the theory of transformative learning is a fundamental theory in education in general and physics education in particular, because the stages of transformative learning are primarily directed at reviewing and revising the frames of reference, "the centrality of experience" to build experiences, and focus on the learner's ability to express and transform experiences into a new meaning. The learner goes through the experience of change as a result of a multi-step process that begins with the presence of a dilemma "a complex problem" that serves as an incentive for the learner to examine his assumptions and beliefs, followed by the use of active learning, practicing critical thinking, self-reflection and discussion with others about assumptions and beliefs to change his perspective or viewpoints (Provident, et al., 2015). These stages can be explained in the context of learning physics in some detail as follows (Baldwin, 2024; Kokkos, 2024; Billings–Padiachey & Motsisi, 2023; Hoggan & Hoggan-Kloubert, 2022; Khupe & Nyamupangedengu, 2024; Mezirow, 2000, 2009):

In the dilemma or problem stage, it is a complex situation that results from a contradiction between the learner's frames of reference or the centrality of experience (ideas, assumptions, beliefs, and alternative perceptions) and the new experiences and concepts that are learned, which leads to a disturbance in the learner's cognitive structures. In the problematic situation, new knowledge and experiences become a challenge to presuppositions. When the learner goes through an experience "learning new physical concepts", this experience "physical concepts" is not quickly accepted; and if it contradicts the centrality of experience or frames of reference (ideas, assumptions, beliefs, and alternative perceptions) that he owns it and that have acquired the power of meaning due to environmental, cultural, personal and social factors; it will be automatically rejected and denied, and then the learner falls into the stage of cognitive disturbance and conflict.

The critical reflective thinking stage involves the learner examining their ideas, assumptions, beliefs, and alternative perceptions, comparing them with new experiences to facilitate transformation. At this point, the learner's thinking becomes independent, and they engage in reflective activities to develop a new understanding of concepts and ideas. This process often creates a sense of imbalance as new experiences challenge existing beliefs, prompting the learner to critically evaluate these assumptions. Through critical reflection, previously inaccurate viewpoints can be identified and changed. Thus, critical reflective thinking is essential for fostering transformative learning experiences and achieving deeper meaning and understanding. Reflection serves as a crucial component of this transformation, requiring learners to cultivate critical self-reflection and the ability to exercise reflective judgment.

The rational discourse stage involves a dialogue centered on the cognitive content, justification, and revision of ideas, concepts, and assumptions through the presentation of evidence, reasoning, and diverse viewpoints. In this process, new perspectives emerge as learners reevaluate their ideas and assumptions through negotiation. Research indicates that when learners participate in community conversations in the classroom and engage in rational dialogue about their ideas, concepts, and experiences while being attentive to the thoughts and feelings of others, they can effectively connect their past experiences with new ones. This engagement fosters significant transformation, resulting in an expanded cognitive structure for the learner.

Generally, The importance and objectives of transformative learning are determined by enhancing the learner's ability to test and validate frames of reference or the centrality of experience, engage in critical dialogue with others, reconcile old and new knowledge, develop self-awareness, build relationships with others, practice reflective thinking about the learner's assumptions and beliefs (Cranton, 2006), and dialogical thinking to open up to new perspectives (Baldwin, 2024; Mezirow, 2009), and build a safe and open environment that allows for the exchange of ideas, reflection on experiences, and exploration of alternative viewpoints; and use learning strategies that enhance the learner's participation in the learning process (Baldwin, 2024; Taylor, 2017). Encouraging him to go beyond his own perspectives and open up to the world, and bringing about a change in his attitudes and feelings towards new knowledge (Hoggan & Finnegan, 2023; Kokkos, 2024), and providing him with opportunities to apply correct knowledge and concepts through an expanded reflective process, thinking about learning, and developing a new sense of confidence and the ability to build new meanings for experience and expertise (Khupe & Nyamupangedengu, 2024).

Research Problem

Acquiring physical concepts is one of the learning goals for physics. Therefore, it's critical to improve students' ability to construct physical notions in a meaningful way (Tolba, 2023). They must be taught in a way that enables them to organize knowledge and ideas in a methodical way so that they are able to refute opposing viewpoints that prevent them from fully understanding physics topics (Decristan et al., 2015).

Previous studies show that students' alternative conceptions limit their ability to learn physics subjects and damage their cognitive structure. It is essential to modify these alternative concepts and apply conceptual change through instructional models that modify and transform previous perceptions within the student's cognitive structure (Heddy et al., 2018; Nadelson et al., 2018; Smortchkova & Shea, 2020; Tolba & Youssef, 2024).

Previous studies have also recommended identifying and correcting alternative concepts among students, and bringing about conceptual change, i.e., enhancing the transformation process to reach the correct physical concepts using teaching models that enhance conceptual conflict within the cognitive structure (Amin et al., 2020; Jiang et al., 2018; Nadelson et al., 2018; Purwanto et al., 2018; Tolba & Youssef, 2024). They also indicated that it is difficult to change these concepts using ineffective traditional methods (Park & Kim, 1998).

Teaching models should also support students' engagement behaviors in learning activities, allow them to participate in the learning process, and exhibit positive attitudes toward learning in order to promote conceptual change. To increase his willingness to resolve conceptual discrepancies, the learner should be motivated by dissatisfaction with preexisting conceptions and have a tendency and desire to engage in complex cognitive processes (Tolba & Youssef, 2024).

Critical thinking is also an essential skill for developing students' ideas, helping them think deeply about alternative issues and concepts, analyzing the problems of understanding physical concepts, and bringing about conceptual change (Hashemi, 2011). Therefore, many studies have indicated the importance of developing critical thinking skills among students through the use of teaching strategies and models that motivate the learner and activate the learner's cognitive construction (Amine et al., 2020; Fajari et al., 2020; Matanlari et al., 2020).

Therefore, TLT posits that learning should lead to a significant transformation in a student's understanding, perspectives, and thinking when engaging with conceptual knowledge. This transformation involves not only rational processes resulting from the development of intellectual tools but also encompasses affective processes (Baldwin, 2024; Billings-Padiachey & Motsisi, 2023; Fleming, 2022; Khupe & Nyamupangedengu, 2024; Maiese, 2017; Taylor, 2017). Mezirow (2009) underscored the importance of emotions, intuition, and imagination, alongside critical thinking and reflection, in facilitating transformative learning. However, the focus should be on teaching that supports the interaction between motivational factors (Engagement in Learning), cognitive aspects (Physical Concepts), and thinking processes (Critical Thinking) (Stevens-Long et al., 2012).

Research Questions

Therefore, the current study made an effort to respond to the following research question: *How does the use of TLT impact students' conceptual change, engagement in learning, and developing critical thinking in the context of physics learning for secondary school students?* This main question is made up of the following questions:

1. What impact does TLT have on secondary school students' conceptual change in physics?

2. What impact does TLT have on the growth of engagement in learning among secondary school students?

3. How can TLT support secondary school students in developing their physics critical thinking abilities?

Research Hypotheses

The current research sought to verify the validity of the following hypotheses:

1. There is no statistically significant difference at the a ≤ 0.05 significance level between the mean scores of the students in the experimental and control groups in the conceptual change test.

2. There is no statistically significant difference at the a ≤ 0.05 significance level between the mean scores of the students in the experimental and control groups in the engagement in learning scale.

3. There is no statistically significant difference at the a ≤ 0.05 significance level between the mean scores of the students in the experimental and control groups in the critical thinking scale.

Procedures

Methodology

Experimental designs play a crucial role in enhancing scientific validity by systematically exploring cause-and-effect relationships between variables. They also ensure both internal and external validity in educational research (Kothari, 2004). Internal validity is essential for determining whether the independent variable (the use of Transformational Learning Theory) is indeed the cause of any observed changes in the dependent variables (conceptual change, engagement in learning, and critical thinking). This involves controlling for potential confounding factors and ensuring that the treatment (Transformational Learning Theory) is responsible for the outcomes. By using experimental designs, researchers can implement rigorous controls to minimize threats to internal validity, such as selection bias, instrumentation, and testing. External validity is equally important because it addresses the generalizability of research findings. It determines whether the results observed in the study can be extended to a broader population. In educational research, this means evaluating whether the effects of a teaching model based on Transformational Learning Theory on academic success and motivation can be observed in students across different settings or contexts. Using experimental designs allows researchers to replicate the study in different educational settings, which can enhance the external validity of their findings. A quasi-experimental approach was used to assess the effect of the independent variable (using TLT) on the dependent variables (critical thinking, engagement in learning, and conceptual change) using a pre-post-test design for the experimental and control groups (Kothari, 2004). Because of this, this study used a quasi-experimental approach. The control group was taught using the conventional method, while the experiment group was taught using TLT.

Participants

The sample for this study was selected using the convenience sampling method, a non-random approach. This strategy allows researchers to select the most accessible participants from the target study population. While convenience sampling may limit the generalizability of results, it enables researchers to easily implement research procedures and collect data efficiently, particularly in school settings where participation is easier to organize (Ekiz, 2013; Etikan et al., 2016). The research sample consisted of sixty-two students from a secondary school in the first grade. Thirty of the students were placed in the experimental group, while thirty-two were placed in the control group. The conceptual change test, the engagement in learning scale, and the critical thinking test were administered to these two groups.

A proposed perspective for implementing transformative learning theory in the context of physics learning

Based on the literature review, the researcher extracts a proposed perspective for implementing the TLT in the context of learning physics as follows (Al Sharifi & Sahib, 2022; Billings–Padiachey & Motsisi, 2023; Fleming, 2022; Kokkos, 2022):

- *Explore and identify alternative Conceptual and perspectives "frames of reference or Centralize the expertise"*: This stage aims to stimulate the learner's cognitive structure and extract the most important alternative concepts towards the physical concepts included in Force in One Dimension Unit (Force and Motion, Contact Forces and Field Forces, Force and Acceleration, Combining Forces, Newton's Second Law, Newton's First Law, Using Newton's laws, Drag Force and Terminal Velocity, Identifying Interaction Forces, Newton's Third Law, Forces of Ropes and Strings, and The Normal Force), which were formed in his own, or as a result of the environment, culture, teacher or reading textbooks (Disorienting dilemmas).
- *Constructing a critical event and creating a conceptual conflict*: This stage aims to generate doubt, confusion, and imbalance, and create cognitive dissonance, conceptual conflict, or internal conflict with the aim of creating an imbalance in the learner's cognitive structures. The contradictory event is represented by the activities that conflict with the alternative concept in the learner's mind, and its interpretation through discussion. It represents the first stage in the process of conceptual change.
- *Seeking concepts and changing alternative conceptions*: At this stage, the learner searches for new knowledge, concepts, and experiences, compares them with alternative concepts, and seeks to resolve the conceptual conflict between them. This stage is the beginning of resolving the conceptual conflict, transforming or changing old frames of reference or the centrality of experience (alternative concepts), and building the correct scientific concepts.
- *Practicing the critical thinking and self-reflection of alternative conceptions*: This stage aims to reconsider knowledge and assumptions and use reflective and critical thinking methods to discover knowledge and evaluate alternative conceptual perceptions, by engaging in an independent thinking process or an internal or rational dialogue. At this stage, alternative concepts and correct physical concepts available in the contradictory event are subject to observation and contemplation. The learner is given sufficient time to think and contemplate, critically evaluate cognitive assumptions (alternative concepts, viewpoints, and mental or intellectual models), and practice reflective thinking, leading to conclusions and correct concepts and bringing about conceptual change.

- *Shaping the learning experience as a process of reconstructing*: Building meaning from new experience: This stage aims to build the learning experience as a process of reconstructing meaning, enhancing the process of building meaning, and engaging in a rational dialogue that focuses on correct physical concepts, and on the process of exchanging experiences and multiple meanings of correct concepts between students. And personalizing knowledge. This stage is defined as giving a new meaning and a new perspective to an old experience, shifting to correct knowledge and concepts, building a new interpretation or revised meaning for a new experience, proposing multiple interpretations related to correct physical concepts, expanding these concepts, clarifying the possibility of applying them in new situations, and making meaningful connections or relationships between them.

Based on these procedures, a guide for physics teachers was prepared explaining how to teach the unit on linear motion (motion in a straight line, motion with uniform acceleration, force, and Newton's laws) in the first-year secondary school textbook. The guide demonstrates how to teach the unit using the Transitional Learning TLT. This guide includes the unit objectives, learning aspects, instructional means, learning activities, and teaching steps in line with the TLT.

Research Tools

The Research Tools Used

1. *The Conceptual Change Test* (CCT) was developed using research from the fields of physics education in particular and science education in general (Badruldin & Alias, 2022; Bello et al., 2018; Gomez-Zwiep, 2008; Heddy et al., 2018; Tolba & Youssef, 2024). The test consisted of twenty-four multiple-choice questions that addressed the linear motion unit (motion in a straight line, motion with uniform acceleration, force and motion, and Newton's laws). The test was presented to a committee of physics education experts to verify its content validity. In terms of the content of the test, most of them agreed. Additionally, a pilot sample of thirty-two students took the test to ascertain the Pearson correlation coefficient and validate internal consistency. At a significance level of 0.05, it was demonstrated that there was a statistical relationship between the conceptual change test items. By computing the Pearson correlation coefficient between the two test halves, which came out to be 0.80, the reliability coefficient of the test was determined using the split-half method. Utilizing the Spearman-Brown prediction equation, which has a high reliability coefficient of 0.91, the adjustment was carried out. It took an average of fifty minutes to complete the test.

2. *Engagement in Learning Scale* (ELS): Studies on learning motivation and engagement served as the foundation for the scale's development (Fuertes et al., 2023; Mai et al., 2023; Tolba & Youssef, 2024), The scale consists of 18 items distributed over three main themes: cognitive (6 items), affective (6 items), and behavior (6 items). A five-point rating system, ranging from 1 to 5, is used for items. Thus, the lowest score was obtained by the student (18 degrees) and the highest score (90 degrees) on the Engagement in Learning Scale. The overall scale's internal consistency coefficient was 0.88, whereas each subscale's range was

0.81–0.92. In the current study, the reliability of the scale was confirmed on a sample of thirty-two students using the Alpha-Cronbach method. The reliability coefficient, according to the results, was 0.86, a high and respectable value. The correlation coefficients between the Engagement in Learning Scale's dimensions, which ranged from 0.67 to 0.78, and between the engagement in learning scale's dimensions and the scale as a whole, which ranged from 0.71 to 0.82, demonstrate the scale's high degree of validity.

3. *Critical Thinking Test* (CTT): The dimensions of the test were determined based on some studies that focused on critical thinking (Chen & Chuang, 2021; Duffy et al., 2022; Fajari et al., 2020; Matanlari et al., 2020). The test consisted of 24 multiple-choice questions, including Knowing the assumptions (6 items), Interpretation (6 items), inference (6 items), and Evaluating Discussions (6 items). In order to determine the Pearson correlation coefficient and confirm the validity of internal consistency, the exam was also administered to a pilot sample of thirty-two students. The split-half approach was used to confirm the test's reliability in the current study, and the results showed that it was equivalent to 0.74. The correction was done using the Spearman-Brown prediction equation, which had a reliability coefficient of 0.91, which is a high reliability coefficient. Additionally, the critical thinking has a high degree of validity, as evidenced by the correlation coefficients between the critical thinking dimensions, which ranged between 0.67 and 0.78, and between the critical thinking dimensions and the test overall, which ranged between 0.71 and 0.82.

Equivalence between the experimental group and the control group in the research tools

To ascertain if the experimental and control groups performed equally on the Conceptual Change test, Engagement in Learning Scale, and Critical Thinking test, a t-test for identify the differences between the experimental and control groups, as shown in Table 1.

Table 1. shows the statistical significance and t-value of the difference between the experimental and control groups' mean scores on the research tools pre-test.

Instruments	Groups	N	Mean	Standard deviation	t- value	Significance Statistical Level
Conceptual Change Test (CCT)	Experiment Group	30	5.03	1.189	1.165	0.349
	Control Group	32	4.75	0.672		
Engagement in Learning Scale (ELS)	Experiment Group	30	21.57	1.455	0.101	0.920
	Control Group	32	21.53	1.295		
Critical Thinking Test (CTT)	Experiment Group	30	5.23	1.165	0.974	0.334
	Control Group	32	5.00	0.672		

Before the pre-performance of the study experiment, Table 1 displays equality between the experimental and control groups. In other words, the average scores of the experimental and control groups in the pre-application of the research tools do not differ statistically significantly.

Results and Discussion

First: The Effect of TLT on Inducing a Conceptual Change in Physics for Secondary School Students

The conceptual change test (CCT) was administered to both the experimental and control groups after the experiment. A t-test was used to determine the difference between the experimental and control groups based on students' scores on the conceptual change test (CCT). Table 2 illustrates this.

Table 2. The t-value for the variations in the experimental and control groups' mean CCT scores.

Test	Groups	N	Mean	Standard Deviation	t-value	Statistical significance	η2	d	Effect size
Conceptual Change Test (CCT)	Experiment Group	30	18.23	1.36	11.71	0.00	0.696	3.03	Large
	Control Group	32	14.56	1.11					

Table 2 shows statistically significant differences at the 0.01 level between the mean scores of the experimental group and the control group in the post-performance related to the conceptual change test as a whole, favoring the experimental group with a mean of 18.23, where $t = 11.71$, $p = 0.01$, and $\eta2 = 0.696$. This indicates that the first null hypothesis cannot be accepted. The effect size ($d=3.03$) is greater than 0.8 for the conceptual change test. This suggests that the experimental treatment (implementing TLT in the context of physics learning) led to conceptual change in physics for high school students. This is because the use of TLT allowed students to investigate, identify, and modify alternative "central" concepts. Applying TLT in the context of physics learning helped students identify pre-existing alternative beliefs and perceptions and re-examine their value and accuracy in light of new physical knowledge and concepts. It also put students in a conceptual conflict between these alternative concepts and the correct physical concepts and motivated them to resolve this conflict through critical self-reflection, examining alternative concepts and ideas, and rejecting pre-existing views and perspectives in favor of new perspectives (Mezirow, 2009; Novak, 2002; Şahin & Dgantay, 2018). That is, implementing TLT in the context of physics learning enabled students to change frames of reference or alternative concepts and select and reconstruct new physical concepts before proceeding to create meaning through new knowledge and experiences (White & Gunstone, 1989).

This result can be interpreted as implementing TLT in the context of physics learning provided a learning environment that enhanced the basic requirements for a conceptual change in students, the most important of which is creating dissatisfaction with incorrect or alternative concepts as a path to creating a conceptual conflict between correct and incorrect physical concepts, creating a state of clarity in which the learner knows the meaning and implications of the concept, creating a state of belief in which the learner believes that the scientific concept is correct and consistent with other accepted concepts, and a state of fruitful production in which the learner becomes able to use correct physical concepts to solve problems that were previously unsolvable (Hewson & Hennessy, 1992; Liu & Nesbitt, 2018; Madu & Orji, 2015; Posner et al.,1982; Tolba & Youssef, 2024; Vosniadou, 2013).

This result supports the importance of employing learning theories that support conceptual change in the educational process, such as the TLT, as it is an educational theory that works to change the educational pattern of the way and manner in which the learner deals with previous experiences and knowledge, and subject them to examination and thinking about them consciously and with critical contemplation, to make a sound decision about them to transform and change them (John, 2016; Maiese, 2017; Mezirow, 2009; Tolba & Youssef, 2024). It also supports the importance of enabling the learner to learn how to free himself from inaccurate ways of thinking that hinder him from making a sound decision to change and transform the perspective from alternative concepts, and work effectively to reach the correct physical concepts, build meaning, and adopt new points of view (Baldwin, 2024)

This result can be attributed to the fact that the stages of TLT (dilemma or problem, critical reflective thinking, and rational discourse) are primarily directed at reviewing and revising the frames of reference “the centrality of experience” or what is known as the alternative concepts that are stable in the learner’s cognitive structure to build experiences and transform them into a new meaning. The learner goes through the experience of change as a result of a multi-step process that begins with the presence of a dilemma “complex problem” that serves as an incentive for the learner to examine his assumptions, beliefs, and alternative concepts, followed by the use of active learning, practicing critical thinking, self-reflection, and discussion with others about it to change his perspective or point of view and shift to the correct physical concepts (Khupe & Nyamupangedengu, 2024; Mezirow, 2009, 2000; Provident et al., 2015).

Second: The Effect of TLT in Developing Engagement in Learning for Secondary School Students

The Engagement in Learning Scale (ELS) was administered to both the experimental and control groups after the experiment. A t-test was used to determine the difference between the experimental and control groups based on students’ scores on the engagement in learning scale (ELS). Table 3 illustrates this.

Table 3. The t-value for the variations in the experimental and control groups’ mean ElS scores.

Engagement In Learning Scale	Groups	N	Mean	Standard Deviation	T-Value	Statistical Significance	η2	D	Effect Size
Cognitive Dimension	Experiment Group	30	23.73	1.62	8.257	0.001	0.532	2.13	Large
	Control Group	32	18.00	3.46					
Affective Dimension	Experiment Group	30	24.43	1.41	7.901	0.001	0.520	2.08	Large
	Control Group	32	19.00	3.51					
Behavior Dimension	Experiment Group	30	25.30	1.34	10.80	0.001	0.660	2.79	Large
	Control Group	32	18.00	3.46					
Engagement In Learning Scale	Experiment Group	30	73.60	3.22	9.846	0.001	0.618	2.54	Large
	Control Group	32	55.00	9.86					

Table 3 shows statistically significant differences at the 0.01 level between the mean scores of the experimental group and the control group in the post-performance related to the engagement in learning scale as a whole, favoring the experimental group with a mean of 73.60, where t = 9.846, p = 0.01, and $\eta 2$ = 0.618. This indicates that the second null hypothesis cannot be accepted.

The results indicate that implementing TLT in the context of learning physics enhanced students' engagement in learning. the explanation for this effect is that TLT plays a role in enhancing the learner's ability to ask questions, participate in rational discussions and dialogue to clarify ideas, insist on participating in activities that support thinking and reflection to explain and clarify correct physical concepts and resolve the conflict between them and alternative concepts, appreciate the value of correct physical concepts in creating meaning and building experiences, and work to develop, expand and enrich the learner's cognitive structures with these experiences, which represent the vital components of engagement in learning (cognitive, emotional and behavioral) (Fredricks et al., 2004; Mai et al., 2023).

The superiority of the experimental group students in engaging in learning can be attributed to the fact that the components of the proposed perspective for applying the TLT in the context of physics learning (exploring and identifying alternative concepts and perspectives, constructing a critical event, creating a conceptual conflict, searching for concepts, changing alternative concepts, practicing critical thinking and self-reflection on alternative concepts, and shaping the learning experience as a reconstruction process) enhanced the learner's motivation, moved his behavior, activated him, and directed him towards learning (Collie & Martin, 2019), and changed his different perspectives on alternative concepts and transformed from them. In the stage of searching for concepts and changing alternative concepts, the orientation towards learning, attention, curiosity, and interest are enhanced (Fredricks et al., 2004; Fuertes et al., 2023; Mai et al., 2023), and the cognitive construction is stimulated and a set of open questions are raised about conceptual perceptions and the identification of these perceptions (Martin & Strozier, 2017). In the stage of practicing critical thinking and self-reflection on alternative concepts, the learner is motivated by the orientation toward mastery, seeks to improve his efficiency and abilities, and the orientation towards mastering the learning task (Ames, 1992; Elliot et al., 2015). In the stage of shaping the learning experience as a process of reconstructing meaning, the learner is motivated by the orientation toward deep processing of knowledge (Collie & Martin, 2019; Elliot et al., 2015).

These results can be interpreted in light of the importance of transformative learning, as previous studies have indicated that transformative learning enhances the learner's ability to engage in critical dialogue with others; develop self-awareness (Cranton, 2006; Tolba & Youssef, 2024), openness to new perspectives (Baldwin, 2024; Mezirow, 2009), build a safe and open environment that allows for reflection and thinking about experiences; use learning strategies that enhance the learner's participation in the learning process (Baldwin, 2024; Taylor, 2017); encourage him to go beyond his perspectives and open up to the world, bring about a change in his attitudes and feelings towards new knowledge (Hoggan &

Finnegan, 2023; Kokkos, 2024), and develop a new sense of confidence and the ability to build new meanings for physical concepts within the cognitive structure (Khupe & Nyamupangedengu, 2024; Martin &Strawser, 2017).

These results are consistent with Mezirow's (2009) vision, where he emphasized the role that emotions and imagination play in transformative learning; and that the individual must be aware and conscious of the ideas associated with the mental schema he possesses; and feel these ideas. These results are also consistent with what recent studies have revealed in that transformative learning includes other aspects aligned with the rational side in the occurrence of the learning process and the construction of meaning, such as emotion and engagement in an active learning process, and transition (Baldwin, 2024; Khupe & Nyamupangedengu, 2024; Maiese, 2017; Taylor, 2017; Tolba & Youssef, 2024). They are also consistent with what Stevens-Long, et al., (2012) indicated that the results of transformative learning are evident in achieving cognitive development, personal development, and behavioral development for the learner, and the ability to think in multiple ways, develop emotional life and create integration between thinking and emotion, and demonstrate cognitive transformation as a rational process accompanied by a process of personal growth and behavioral integration.

Third: The Effect of TLT in developing critical thinking in physics for Secondary school students

The Critical Thinking Test (CTT) was administered to both the experimental and control groups after the experiment. A t-test was used to determine the difference between the experimental and control groups based on students' scores on the CTT. Table 4 illustrates this.

Table 4. The t-value for the variations in the experimental and control groups' mean CTT scores.

Critical Thinking Test (CTT)	Groups	N	Mean	Standard Deviation	t-value	Statistical significance	η2	d	Effect size
Knowing the assumptions	Experiment Group	30	4.27	0.69	2.80	0.01	0.15	0.84	Large
	Control Group	32	3.78	0.71					
Interpretation	Experiment Group	30	4.43	0.57	5.57	0.01	0.341	1.44	Large
	Control Group	32	3.59	0.61					
Inference	Experiment Group	30	3.80	0.71	3.28	0.01	0.152	0.85	Large
	Control Group	32	3.28	0.52					
Evaluating Discussions	Experiment Group	30	4.20	0.55	7.30	0.01	0.470	1.88	Large
	Control Group	32	3.16	0.57					
Critical Thinking Test	Experiment Group	30	16.70	1.88	6.18	0.01	0.389	1.59	Large
	Control Group	32	13.81	1.80					

Table 4 shows statistically significant differences at the 0.01 level between the mean scores of the experimental group and the control group in the post-performance related to the learning motivation scale as a whole, favoring the experimental group with a mean of 16.70, where $t = 6.18$, $p = 0.01$, and $\eta2 = 0.389$. This indicates that the third null hypothesis cannot be accepted. The effect size (d=0.84; 1.44; 0.85; 1.88; 1.59) is greater than 0.8 for each critical thinking skill. The results indicate that implementing TLT in the context of physics learning led to the development of critical thinking in physics. This is because implementing the TLT in the context of learning physics helps students to self-reflect and think critically by exchanging views on physical problems and investigating them while employing all critical thinking skills (knowing assumptions - interpretation - inference - evaluating discussions) to reach the answer based on evidence and proofs.

These results also support the findings of previous studies that critical thinking in science can be developed among students using learning strategies and models that focus on the learner. It gives him the freedom to explore content, analyze sources, and apply information to develop critical thinking skills (Amin et al., 2020; Aydın Gürler & Kaplan, 2023; Billings–Padiachey & Motsisi, 2023; Çetin, 2020; Matanlari et al., 2020).

This result can also be interpreted as implementing the theory of transformative learning in the context of learning physics works to develop two distinct abilities that represent the basis for transformative learning, namely: developing the ability to practice critical self-reflection, and the ability to practice reflective decision-making or judgment, and within them critical thinking skills are practiced when learning and examining the content or conceptual knowledge included in Force in One Dimension Unit, and reflecting on and describing the problem and the conceptual issues within it, and reflecting on the thinking processes themselves (Al Sharifi & Sahib, 2022; Deringöl, 2019).

This result supports the fact that implementing the TLT in the context of learning physics enhanced the learner's practice of critical thinking skills when learning physical phenomena; since transformative learning supports self-examination, critical evaluation of physical concepts and ideas within the learner's cognitive structure, discomfort with these concepts and ideas, their inadequacy in solving physical problems, exploring options, building competence and self-confidence, planning, and acquiring knowledge (Brock, 2010; Owen, 2016; Santalucia & Johnson, 2010). It also allows the learner to freely express his ideas, generate high levels of thinking, put the learner at the heart of critical dialogue, overcome his preconceived ideas and discover life from a different perspective, enhance his ability to analyze arguments and discussions and determine what can be accepted or rejected (Facione, 2015; Page & Mukherjee, 2007) and give him sufficient opportunities to engage in building arguments and discussions and asking questions to reach a deep understanding of physical concepts (Osborne, 2014).

The low performance of the control group students in critical thinking skills can also be attributed to the inability of traditional teaching methods to enable the individual to learn how to free himself from unconscious ways of thinking that hinder him from making decisions and constructing meaning (Mezirow, 1999), the weak ability to practice critical thinking skills responsible for changing mental plans and producing and expanding meaning, and the failure to build multiple interpretations of scientific concepts, and thus the cognitive structures and mental plans of students are not modified and become inactive and unable to absorb new physical concepts (Tolba, 2023; Tolba & Youssef, 2024). This is consistent with what Karahan et al. (2023) indicated that the existing teaching systems and practices constitute a major obstacle to students' failure to acquire critical thinking skills.

Conclusion, Recommendations, and Suggestions for Further Research

The results support the effects of transformational learning theory in the context of physics learning to induce conceptual change and develop engagement in learning and critical thinking. In light of the results of this research, many recommendations were presented, including directing physics curriculum planners and developers to develop physics curricula in light of the main ideas of the TLT, which enhance the growth of physical concepts, modify alternative perceptions, and develop engagement in learning and critical thinking skills among learners. Enriching physics curricula with scientific activities and educational situations that stimulate the cognitive structure, enhance transformation (modification), and cognitive engagement, and stimulate critical thinking skills among students. Activating teaching strategies and models using the TLT to develop physical concepts, motivation, and critical and reflective thinking skills. Holding workshops and training courses for teachers to train them on implementing the TLT in the context of learning physics to discover physical concepts and alternative perspectives (the centrality of experience), work to change and transform them, and build meaning for new physical experiences for students.

Several suggestions are also presented, including conducting further research in physics teaching, such as investigating the effects of TLT in the context of physics learning to develop students' reflective and inquiry thinking, self-efficacy, and self-regulated learning skills, and investigating the effects of TLT in the context of physics learning to develop physics concepts, academic persistence, physics problem solving, and investigating the effect of proposed teaching models based on TLT in developing scientific concepts, information processing skills, and self-efficacy beliefs among middle school students.

Conflict of Interests

The author acknowledges and declares that there is no potential conflict of interest regarding the authorship and publication of the current study.

The data availability statement

Data cannot be shared openly, but are available on request from the author.

Ethical considerations

All respondents understood that participating in this study was voluntary, and they could decide to withdraw at any time. Furthermore, participants were informed that their responses would only be used for a research study and that their identities would not be revealed.

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