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Impact of a teaching-learning sequence on surface phenomena in liquids on growth mindset development of high school students

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Abstract

This paper explores aspects of a broader study focused on the planning and pilot implementation of two teaching-learning sequences (TLSs) for high school students, centered on surface phenomena in liquids. These TLSs are inspired by inquiry-based and investigative learning approaches. Understanding surface phenomena is crucial not only in physics but also in various scientific and technical fields. We chose this topic because traditional teaching methods often fail to engage students effectively and overlook the importance of their learning processes and beliefs, which limits opportunities for developing a growth mindset. After outlining results of a qualitative (thematic) analysis of interviews aimed at examining the impact of the didactic paths on students' growth mindset development, we present key findings of this analysis. The results suggest that student-centered TLSs can foster key aspects of growth mindset, such as increased confidence, greater willingness to tackle challenges, and enhanced engagement even when a full mindset shift does not occur.

Keywords: growth mindset, qualitative research, surface phenomena, teaching-learning sequence, thematic analysis

INTRODUCTION

In recent decades, science education research has increasingly focused on the design and implementation of teaching-learning sequences (TLSs), research-informed instructional paths that aim to support meaningful learning through the integration of scientific knowledge with learners' perspectives (Méheut & Psillos, 2004; Psillos & Kariotoglou, 2016). TLSs are often grounded in constructionist principles, emphasizing active student engagement through inquiry, modelling, and reflective practice (Méheut & Psillos, 2004). Among the theoretical frameworks guiding TLS design, the educational reconstruction model (Duit et al., 2012; Kattmann et al., 1996) is notable for linking scientific content analysis with educational considerations, including students' preconceptions and learning processes.

Within this context, active learning approaches such as those proposed in the investigative science learning environment (Etkina, 2023) have shown potential to enhance students' engagement, knowledge, reasoning, valuation and self-efficacy (Ainley & Ainley, 2011; Cannady et al., 2019; Malone, 2023). These approaches align with constructionist views of learning, which emphasize knowledge construction through authentic tasks, social collaboration, and iterative sensemaking (Herrington & Oliver, 2000). An emerging line of inquiry in science education explores how such learning environments may also support the development of a growth mindset that is, the belief that abilities can be cultivated through effort and learning (Dweck, 2006, 2017). Research indicates that active learning environments, particularly those where teachers model and support growth-oriented beliefs, can positively influence students' mindsets, engagement, academic achievement and epistemic beliefs. For instance, a study by Vestad and Bru (2023) found that teacher support for growth mindset was directly related to students' own mindset beliefs, which in turn were associated with increased academic engagement and achievement. Yeager and Dweck (2012) emphasize the importance of embedding growth mindset interventions within supportive contexts, highlighting the role of teachers and of school climate in shaping students' beliefs,

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Contribution to the literature

- This study bridges modeling-centered instructional design with growth-mindset development in science learning.
- The study shows how the use of thematic analysis can help track and study the development of students' mindsets as they participate in a given instructional intervention.
- The study shows how student-centered TLSs can effectively nurture important facets of a growth mindset, such as confidence, a inclination to engage with challenges, and increased overall participation, even in scientifically challenging domains.

mindsets and outcomes. These findings suggest that fostering growth mindset in students is not solely about individual interventions but also involves creating an educational environment that consistently reinforces the value of effort, learning from mistakes, and embracing challenges. Moreover, as reported by Kalman and Lattery (2018), active learning strategies help address diverse student epistemologies by prompting learners to critically examine their own ideas, discuss them with peers, and develop a more coherent and sophisticated understanding of scientific knowledge. A systematic review of growth mindset intervention effects can be found in Burnette et al. (2023).

This study investigates how a TLS cantered on a challenging scientific content and structured through active learning approaches may contribute to the development of growth mindset in high school students. To this end, the study presented in this paper addresses the following research question:

To what extent can TLSs centered on scientific topics and implemented through modelling-based approaches cultivate growth mindset in students?

GROWTH MINDSET AND ACTIVE LEARNING ENVIRONMENTS

To answer this research question, we must examine how students' mindsets are influenced and shaped through the learning experience. Cognitive psychology studies reveal that the way students view their own skills can play a crucial role in shaping their engagement, motivation and achievements in learning (Dweck, 2006, 2017). A central distinction is between learners who hold a "fixed mindset", believing that abilities are innate and unchangeable, and those who embrace a "growth mindset", viewing abilities as malleable and improvable through effort and learning strategies (Dweck, 2006, 2017). In science education, this distinction has important pedagogical implications. Students with a growth mindset are more likely to pursue mastery-oriented goals, seek constructive feedback, and persist in the face of challenges (Yeager & Dweck, 2012). They tend to attribute failure to controllable factors such as effort or strategy use, rather than to a lack of ability, and actively engage in identifying new ways to learn. In contrast, students with a fixed mindset often prioritize performance goals, interpret failure as a reflection of inherent limitations, and are more likely to disengage when confronted with difficulties (Yeager & Dweck, 2012). Evidence suggests that students with a growth mindset are better positioned to achieve deep and meaningful learning outcomes (Zhang et al., 2017). This orientation encourages deliberate and reflective practice, particularly when learners are supported in moving beyond their "zone of cognitive comfort" representing the space of familiar tasks that require minimal effort and yield limited growth (Pelley, 2014). When students believe in their capacity for improvement, they are more likely to invest time in challenging tasks, persist through difficulties, and develop more expert-like learning behaviors. Through deliberate practice, a process of targeted, iterative effort aimed at progressively higher levels of competence (Ericsson, 2007), students develop self-awareness about their learning processes, recognize their strengths and limitations, and refine their problem-solving strategies. These practices support not only cognitive gains but also the development of metacognitive skills and self-efficacy.

TLSs based on active learning environments can offer students rich opportunities for cultivating growth mindset by prioritizing effort, feedback, and intellectual risk-taking, factors that support both academic success and long-term motivation. Moreover, modelling-based learning environments can help students iteratively test ideas, reflect on processes, and see effort as central to learning. Through mechanisms such as building confidence, reflecting strategically, and persisting trough challenges, modelling activities can effectively cultivate aspects related to growth mindset development. Research on modelling instruction supports the idea that students involved in model building and simulation-based activities report increased self-efficacy and more expert-like beliefs about learning (Hidayat & Ramli, 2019; Hough et al., 2019). This aligns with the growth mindset principle that abilities develop through sustained effort and reflection (Ericsson, 2007).

Additionally, studies (e.g., Guo, 2012; Maisaroh & Farozin, 2020) show that metacognitive prompts embedded in modelling-based tasks, such as comparing predicted and actual outcomes, enhance students' reflective practices and empower them to revise misconceptions rather than retreat from difficulty. It is worth noting that some studies report declines in self-efficacy even if students' engagement and conceptual understanding rise (Dou et al., 2018; Ouweneel et al. 2013). While this might seem counterintuitive at first glance, from a growth-mindset lens it can be interpreted as students recalibrating their sense of competence as they recognize the true nature of scientific inquiry marked by iteration, uncertainty, and cognitive challenge. Malone and Schuchardt (2023) found that students with lower initial reasoning skills showed the greatest gains after prolonged engagement with modelling-based curricula, suggesting that these environments, through experiences of effortful success, are especially powerful for cultivating a growth mindset among learners who may lack confidence.

THE RESEARCH

TLSs For Promoting Growth Mindset

This paper explores a specific aspect of broader research focused on the design and pilot testing of two TLSs developed for upper secondary school students on the topic of surface phenomena. This topic, while central to physics, also has significant relevance across various scientific and technological fields due to its interdisciplinary nature and wide range of applications. At the same time, it presents substantial conceptual challenges for learners, making it particularly suitable for promoting the development of a growth mindset. Engaging with complex and unfamiliar content provides opportunities for students to embrace challenges, build resilience, and refine problem-solving strategies, skills that are closely tied to positive learning beliefs and academic perseverance (Dweck, 2017; Stohlmann, 2022). Traditionally, surface phenomena are introduced through transmissive teaching methods that emphasize macroscopic descriptions and, at more advanced levels, molecular interactions. However, prior research highlights the limitations of traditional approaches to introducing challenging topics such as surface phenomena, which often fail to actively engage students or foster deep understanding (Marchand et al., 2011), ultimately hindering the development of a growth mindset.

To overcome these limitations, we designed two TLSs specifically focused on surface phenomena that adopt interactive, student-centered strategies, including laboratory experiments, computer simulations, and collaborative learning, to promote conceptual engagement and support more adaptive learning dispositions. Beyond enhancing content knowledge, the TLSs (more detailed information about the TLSs implemented will be provided in the following section) were intentionally designed to support broader aspects of student learning, such as metacognitive reflection and the development of productive learning habits, both of which are closely tied to fostering growth mindset.

Inquiry-based tasks encourage autonomy by requiring students to make decisions about how to conduct experiments and interpret results, thus creating opportunities to reframe mistakes as part of the learning process. Collaborative problem-solving plays a central role: working in small groups, students generate hypotheses, interpret experimental data, and compare their predictions with observed outcomes, an approach that emphasizes the social construction of knowledge and reinforces the idea that learning is not based on fixed ability but grows through effort and interaction. Simulations and modeling tools further support a trial-and-error learning process, with opportunities to revisit and refine their approaches, reinforcing the idea that understanding develops progressively. In our TLSs reflection was embedded throughout the sequences via open-ended questions and feedback questionnaires that encouraged students to evaluate how their understanding evolved, identify effective learning strategies, and articulate any changes in their attitudes toward science. These moments fostered metacognitive awareness and helped reinforce beliefs aligned with growth mindset, which are essential for promoting deeper and more resilient forms of learning, as they enable students to take ownership of their learning processes and persist in the face of difficulty.

In recognizing that "learning promotion" is a multifaceted concept involving cognitive, motivational, social, and metacognitive dimensions, we conducted an extensive literature review to identify key aspects emphasized in educational research (Marzano, 1992). As discussed in depth elsewhere (Fazio et al., 2023; Termini, 2023), we developed a conceptual framework that articulates three central dimensions of learning: acquisition of conceptual knowledge, intellectual development, and the development of habits of mind that support science learning. Each dimension of learning is further detailed through subdimensions such as metacognition, well-being in learning, self-efficacy, and growth mindset (Cohen, 2006; Dweck, 2017; Hacker et al., 2009; Stohlmann, 2022; Zimmerman, 1995). These dimensions are closely tied to the idea of promoting science learning in a comprehensive way, accounting not only for content mastery but also for students' ability to reflect on their thinking, regulate their learning, and persist in the face of challenges. This paper focuses specifically on the development of growth mindset, analyzing how students' beliefs about learning are influenced through direct engagement with the TLSs. Drawing on students' own words and reflections, we examine how active, student-centered, model-based experiences embedded in the TLSs helped shape their views on learning, effort, and their capacity to overcome difficulties.

TLSs Activities

The TLSs were designed to foster conceptual understanding and promote growth mindset by engaging students in both qualitative and quantitative experiments alongside modeling activities. Both TLSs incorporated hands-on qualitative experiments, where students observed surface phenomena such as droplet formation and liquid behavior on different surfaces. These observations encouraged students to identify patterns, formulate hypotheses, and reflect deeply on concepts like surface tension, cohesion, and adhesion through guided, open-ended questions. A key difference between the TLSs lies in their modeling approaches. TLS-A adopted a macroscopic perspective aligned with traditional curricula, where students used large-scale visual representations, such as diagrams or simple computational models to simulate cohesion and adhesion (Termini, 2023). Students manipulated macroscopic variables and observed outcomes like droplet shapes and contact angles, focusing on accessible, high-level descriptions. Conversely, TLS-B employed a mesoscopic approach, representing liquids as systems of interacting particles governed by attractive and repulsive forces (Battaglia et al., 2024; Fazio et al., 2023). Through computer simulations, students are allowed to adjust parameters like interaction strength and inter-particle distance to explore the mechanisms underlying surface tension and wetting, effectively bridging macroscopic phenomena and molecular-level interactions (Besson & Viennot, 2004). In both TLSs, students also conducted quantitative experiments, collecting real-time data such as contact angles and droplet sizes. These measurements allowed them to validate and refine their models while exploring experimental uncertainty, data interpretation, and the connection between theory and practice. In TLS-B the combination of computer-based simulations and real-time experiments enabled students to engage in model-based reasoning by manipulating variables and testing hypotheses across multiple levels of representation (Develaki, 2017; Rutten et al., 2012). Both approaches emphasized iterative refinement and critical thinking, encouraging students to continuously adjust their models based on experimental results. Further details on the design and implementation of these TLSs can be found in Fazio et al. (2023) and Termini (2023).

The Student Sample

The TLSs introduced in the previous paragraph were implemented during the 2021/22 school year with two groups of fourth-year students from a science-oriented Italian upper secondary school (liceo scientifico). The TLSs involved a total of 40 students (aged approximately 16-17), drawn from three parallel classes following the same curricular program in physics. To ensure a balanced distribution of abilities and attitudes, students were randomly assigned to one of the two groups: group A, which followed the macroscopic TLS-A, and group B, which followed the mesoscopic TLS-B. Each group comprised 20 students and reflected a diversity of prior knowledge, interest in science, and learning dispositions, as reported by their teachers and confirmed by initial classroom observations. This random assignment was intended to minimize pre-existing group differences and to ensure that any observed variations in student engagement or learning outcomes could be more confidently attributed to the specific features of the TLSs, particularly the different modeling approaches adopted.

Data Collection

During the implementation of the TLSs, multiple forms of data were collected, including students' responses to content questionnaires, worksheets, interview transcripts, audio recordings of group discussions, and classroom observations made by researchers. For the purposes of this study, we focused specifically on interviews conducted with a sub-sample of students to investigate the development of growth mindset. Ten students from both group A and group B were initially selected based on their greater willingness, compared to their peers, to reflect deeply on their learning experiences and articulate how they had engaged with the proposed activities. These students showed a particular interest in discussing not only what they had done, but how they had approached the learning process. They offered thoughtful reflections on changes in their attitudes toward physics, their self-perception as learners, and their ability to manage challenges. These insights proved especially valuable for examining how the TLSs contributed to shifts in learning beliefs, including increased confidence, persistence, and a growing appreciation of science as an exploratory, collaborative discipline. Because of their depth of engagement, these students' accounts were particularly informative for analyzing the impact of the TLSs on the development of growth mindset. The interviews consisted of five questions designed to prove whether and how students' beliefs about learning and intelligence had evolved through their participation in the TLSs. From this sample, we selected three students for in-depth analysis–student 1 from group B, and student 2 and student 3 from group A–who represent distinct mindset profiles. Their responses offered valuable insights into how different instructional approaches and learning activities contributed to shaping their beliefs about learning. By focusing on this subset, we aimed to explore how students with varying initial dispositions responded to the learning experiences provided by the two TLSs. The analysis of these interviews allowed us to address our central research question:

To what extent can TLSs cantered on scientific topics and implemented through modelling-based approaches cultivate growth mindset in students?

This focused investigation helped us better understand how engagement in hands-on, inquiry-driven activities, particularly those structured around macroscopic and mesoscopic models of surface phenomena can influence students' beliefs about their ability to learn and improve over time (i.e., their fixed- or growth -oriented mindset).

Thematic Analysis of Students' Interviews

The data gathered from the brief interviews conducted with three students from the sample overall were subjected to thematic analysis (Boyatzis, 1998; Braun & Clarke, 2006). Although the small amount of data and the limited number of questions posed to students might constrain the effectiveness of thematic analysis in this context, it provided valuable insights beyond what a simple keyword count or reading could reveal. Thematic analysis, a qualitative research method, focuses on identifying and interpreting patterns or themes within a dataset. It involves coding and categorizing information to uncover emerging themes, particularly useful in exploring individual or group perspectives, experiences, and meanings in educational research. This method helps identify aspects of student learning that might be overlooked by quantitative approaches.

In our study, we relied on previously identified overarching codes (Fazio et al., 2023; Termini, 2023), which were used to guide the interviews analysis. These overarching codes were developed by grouping raw codes (or initial codes) from the broader investigation of promoting science learning. After several rounds of reading the data, the three researchers involved in the study reached a consensus that certain initial codes could be merged based on shared patterns. These overarching codes helped synthesize the data and identify key themes related to the development of growth mindset, which was central to this study.

To conduct the coding process, the researchers adopted an inductive strategy, generating codes based on insights drawn from the qualitative data, rather than using a pre-existing codebook (Boyatzis, 1998). This allowed us to identify relevant patterns and concepts that emerged directly from the data.

To ensure reliability, the three researchers independently conducted the coding process, and through regular meetings, reached interrater agreement. This collaborative approach helped minimize subjective bias and ensure consistency in the coding process. By discussing and refining the codes together, the researchers reached consensus on how to label and group them into broader themes. This method enhanced the validity of the findings (Braun & Clarke, 2006) and provided a comprehensive and well-grounded interpretation of the data.

While the limited number of interviewees and the brief structure of the interviews protocol could be seen as constraints, thematic analysis allowed us to move beyond surface-level descriptions and identify significant insights that would not have emerged through simple keyword analysis or reading alone. This method focuses on systematically coding and interpreting qualitative data to uncover themes that reveal how individuals understand and experience phenomena, in this case, the development of growth mindset within an educational context. Our analysis was guided by a set of overarching codes identified in a broader investigation on promoting science learning (Fazio et al., 2023; Termini, 2023). These codes were developed by clustering initial codes that had emerged during previous cycles of data analysis. Through several rounds of reading and collaborative discussion, we reached a consensus on how to consolidate and refine these codes based on recurrent patterns in the data. These overarching codes provided an interpretative framework for analyzing how the TLSs supported changes in students' learning beliefs and attitudes, particularly about the development of growth mindset.

Table 1 provides an overview of the overarching codes used in this study, each accompanied by a concise name that captures its core theme and supports clarity, as indicated in **Table 1** caption.

The Interviews

To explore how students' mindsets evolved through participation in the TLSs, we conducted semi-structured interviews with a subsample of students. The interview protocol was specifically designed to investigate whether and how students developed a growth mindset in response to the proposed learning activities. Semi-structured interviews were chosen to balance consistency across participants with the flexibility needed to explore individual experiences in depth. Each interview lasted approximately 20-30 minutes and was audio recorded and transcribed for subsequent thematic analysis. The interview protocol consisted of five open-ended questions prompting students to reflect on their learning process, their reactions to difficulties encountered during the activities, their perception of progress, and any changes in their self-image as learners of science. Follow-up questions were asked when necessary to clarify or deepen responses, allowing students to elaborate on meaningful aspects of their experience. This format provided rich, qualitative insights into students' thinking, enabling the identification of nuanced shifts in beliefs about learning and intelligence. The semi-structured nature of the interviews also made it possible to compare students' responses across common themes while capturing personal interpretations and trajectories.

Table 1. Overview of the overarching codes used in the analysis: (A) learning conditions, (C) critical thinking through debate, (E) reflective awareness, and (F) engagement with interactive methods, along with their detailed descriptions

Merged raw codes	OC	Description
Procedures-methodologies, tools-skills, theory VS practice, traditional lecture VS innovative lecture	A	Students provide feedback on the activities, tools, situations, or factors that either facilitate or obstruct their understanding of subjects. Supportive elements may include interactive exercises, visual aids, clear explanations, and a constructive learning environment. Conversely, challenges can arise from complex language, insufficient engagement, and an excessive amount of information. Students emphasize the importance of practical applications of theoretical knowledge, as well as the advantages of dynamic, interactive, technology-enhanced lectures.
Debate, perspective, role	C	Students understand that participating in debates is essential for enhancing their critical thinking, communication skills, exposure to diverse perspectives, and self-confidence. Through debate engagement, they broaden their understanding of various topics by reflecting on contrasting viewpoints, which promotes empathy, tolerance, and an appreciation for diversity. Additionally, exploring opposing opinions helps students refine their critical thinking abilities, identify biases, and develop well-informed viewpoints.
Reflection, acknowledgement	E	Reflecting on their progress is a vital component of the learning experience for students. It allows them to assess their development, identify aspects that require improvement, and enhance their understanding of the knowledge and skills acquired. Through a critical examination of the pros and cons of various activities, students can recognize the significance of their efforts and uncover areas for growth. This reflection also enables them to identify their strengths and weaknesses, fostering a clearer understanding of how to apply their knowledge and skills in real-world situations.
Engagement-interest, comfort, proactiveness	F	Students generally prefer computer-based simulations and hands-on experiments over traditional methods because they are more engaging and challenging. These interactive approaches encourage a deeper understanding of the material, spark interest, and foster critical thinking skills, which ultimately makes learning more enjoyable. Many students find that participating in hands-on activities greatly improves their understanding of the subject.

Note. OC: Overarching code

In previous work (Termini et al., 2024), we presented a thematic analysis of interviews conducted with a group of students to investigate the development of a growth mindset. In this paper, we extend that analysis by focusing on the responses of a different sample who completed the same interviews protocol. Our aim is to show how thematic analysis was applied to identify the students' growth mindset profiles. This section reports the five interviews' questions administered and the responses provided by the selected students. For each question, a dedicated table is presented, including the question text, the full responses from the students, and the associated overarching codes, which help identify the dimensions of learning involved. Each excerpt was coded using the overarching codes A, C, E, and F, facilitating the identification of segments containing relevant information on specific aspects of learning (**Table 2**).

To illustrate our coding process, we provide an example of how a specific data segment was labelled according to the overarching codes based on their alignment with the theoretical framework.

Table 2. Questions and responses

S	Response	OC
Question 1. What was your attitude towards scientific disciplines before taking part in these activities?		
S1	"I had a good relationship with these subjects, with Math being my favorite. I generally found solving exercises and problems quite manageable. I was also good at physics and science, though initially, I doubted my ability to conduct an experiment on my own, mainly because I had never done one independently at school. The most I had experienced was watching videos of experiments or observing a professor perform them."	E, F
S2	"My relationship with scientific subjects was rather neutral. I found them interesting, even though I felt I lacked a natural aptitude for them, particularly in chemistry and physics."	E, F
S3	"I had a positive relationship with scientific subjects, though I didn't enjoy them all equally. For instance, I preferred biology over physics because I found it easier and quicker to understand."	E, F
Question 2. Which activities of the TLSs did you find most interesting and/or useful? Explain why.		
S1	"I enjoyed computer-based simulation, as I found it fascinating to observe how the system evolved when I adjusted the simulation parameters. The graphical representation of the system, generated by the simulation, helped me better understand the concepts I was studying."	A, E
S2	"Overall, I found all of them interesting. Seeing things in practice was engaging, even though I faced some challenges in conducting the experiments on my own, as I had never done them this way before."	A, E

Table 2 (Continued).

S	Response	OC
S3	"I had a good relationship with these subjects, with Math being my favorite. I generally found solving exercises and problems quite manageable. I was also good at physics and science, though initially, I doubted my ability to conduct an experiment on my own, mainly because I had never done one independently at school. The most I had experienced was watching videos of experiments or observing a professor perform them."	E, F
Question 3. Did the activities you took part in help you in acquiring skills you didn't possess before? If yes, which ones and in which contexts did you find them useful?		
S1	"I developed the ability to collaborate in a group and share my thoughts, even when others have different opinions. Additionally, I learned that conducting an experiment requires precision and following the correct steps to obtain meaningful results. For instance, I became aware of the importance of using proper units of measurement when taking measurements."	A, C, E, F
S2	"I'm not sure, I still feel quite insecure. I don't think I could conduct an experiment on my own or fully understand its results. However, discussing with my group members during the experiment was helpful."	A, C, E, F
S3	"These activities made me realize that I knew much less than I had believed, both in terms of the topic and the study and analysis methods. Before participating, I was convinced that if I didn't understand something immediately, I would never get it. I thought I always needed an instant solution to problems. However, thanks to my group mates, I understood that collaborating with others can greatly enhance my understanding of even the most challenging topics. I had also believed that working alone saved time, but I was just avoiding in-depth study, which led to wasted opportunities for learning."	A, C, E, F
Question 4. Did you ever feel uncomfortable during the activities? If yes, when?		
S1	"No, I've always felt at ease talking with my group mates, those from other groups, and even the teachers, because this is an environment that encourages dialogue."	E, F
S2	"Yes, when I had to present the results in front of all the groups, I felt a bit anxious and struggled to explain clearly what we had discussed. Honestly, I preferred when other group members took on the task of presenting the results."	E, F
S3	"At first, when I couldn't find the answers I was looking for, I became a bit nervous. I wasn't accustomed to this new approach of gradually finding answers step by step. Initially, I didn't feel very comfortable working with others, but eventually, I came to enjoy it and found it very helpful."	E, F
Question 5. After taking part in these TLSs, has your attitude towards scientific disciplines changed? If yes, how?		
S1	"I've always had a positive attitude towards scientific disciplines. However, now I feel more confident in my ability to understand even the more challenging topics, as long as I put in the effort to study and analyze them thoroughly, discuss them with others, and approach them from different perspectives, such as through experiments or simulations, not just through mathematical calculations."	E, C, F
S2	"I'm not sure if anything has really changed. I never thought I had a talent for these subjects, and I still feel the same way. It's not because of the activities we did, which were interesting, but rather because of my own perspective. I still find scientific subjects intriguing, and maybe they no longer seem impossible to grasp, but I'm still convinced I'm not particularly good at them."	E, C, F
S3	"Yes, completely. I'm even starting to enjoy subjects I used to find more challenging, like physics. My attitude towards scientific subjects has changed a lot, depending on how I approach them. For example, I used to think that if I didn't understand something right away, I shouldn't waste time trying to figure it out, and I convinced myself that I didn't care. Now I realize that the approach was wrong. I believe that with effort, discussions with classmates, or trying different experiments, even a complex topic, not just physics, can be understood and become interesting."	E, C, F

Note. S: Student & OC: Overarching code

We assigned the codes E (metacognitive awareness), C (engagement in scientific practices), and F (development of productive learning habits) to student 1's response to Q5 based on specific textual elements that clearly reflect the identified theoretical dimensions (Fazio et al., 2023; Marzano, 1992). In particular, the reference to "putting in the effort to study, analyzing thoroughly, and discussing with others" demonstrates an awareness of one's own learning processes and a strategic approach to learning, which supports the assignment of E. The mention of "experiments and simulations" as complementary ways to understand complex concepts indicates active involvement in scientific practices, justifying the code C. Finally, the reported change ("now I feel more confident ... even with more difficult topics") and the openness to different approaches reflect the development of learning-oriented and persistent habits of mind, corresponding to the code F.

STUDENTS' PROFILES

The thematic analysis of the interviews data enabled us to explore whether and how the students involved in the study developed a growth mindset through their participation in the TLS activities. Each student profile was reconstructed based on insights that emerged from the thematic analysis of their interview responses. In the following section, we describe each student profile in relation to the growth mindset, indicating which specific parts of the interviews contributed to the identification of aspects of their mindset development. To establish each student's initial mindset profile, we did not rely on a standardized questionnaire administered before the TLS implementation. Instead, we adopted a triangulated approach, systematically drawing on multiple sources of qualitative data. These included classroom observations conducted by researchers, students' written responses to pre-activity questionnaires and worksheets from the broader study, and detailed input from the students' physics teacher. By cross-referencing these diverse data sources, we were able to identify coherent patterns in students' attitudes toward learning challenges, their persistence when facing difficulties, and their beliefs about their capacity to improve in science. This approach allowed us to build robust, evidence-informed profiles of students' starting mindsets, thereby enhancing the interpretive validity of our analysis.

Student 1

Student 1 exhibits a positive attitude towards scientific disciplines from the start. However, despite his interest and quick comprehension of scientific topics, he initially lacks confidence in addressing and solving complex issues and tasks (i.e., he initially shows a fixed mindset). He doubts his ability to conduct hands-on experiments and struggles with interpreting the resulting data. Consequently, he tends to focus his efforts on tasks he believes he can manage well, remaining within his comfort zone:

> I had a good relationship with these subjects, with math being my favorite. I generally found solving exercises and problems quite manageable. I was also good at physics and science, though initially, I doubted my ability to conduct an experiment on my own, mainly because I had never done one independently at school. The most I had experienced was watching videos of experiments or observing a professor perform them.

After participating in TLS activities, his mindset begins to shift. He mentions that one of the most helpful tools for his learning has been computer-based simulation, which allowed him to observe the progression of the physical system under study:

> I enjoyed computer-based simulation, as I found it fascinating to observe how the system evolved when I adjusted the simulation parameters. The graphical representation of the system, generated by the simulation, helped me better understand the concepts I was studying.

Through quantitative experimental activities and the conscious use of computer modelling, he has recognized the significance of methodological rigor in conducting meaningful experiments and accurately interpreting the collected data. Additionally, he finds discussions with peers and researchers about his progress and results to be beneficial and constructive, showing an increase in his personal confidence:

> I developed the ability to collaborate in a group and share my thoughts, even when others have different opinions. Additionally, I learned that conducting an experiment requires precision and following the correct steps to obtain meaningful results. For instance, I became aware of the importance of using proper units of measurement when taking measurements. No, I've always felt at ease talking with my group mates, those from other groups, and even the teachers, because this is an environment that encourages dialogue.

Now, the student expresses greater confidence in his ability to understand more complex topics, provided he dedicates time to studying and analyzes them thoroughly and engages in discussions with others. He begins to approach these topics from multiple viewpoints, including experimental and simulation perspectives, rather than solely relying on mathematical calculations. Consequently, by the conclusion of the activities, he appears to have started developing a growth mindset:

> I've always had a positive attitude towards scientific disciplines. However, now I feel more confident in my ability to understand even the more challenging topics, as long as I put in the effort to study and analyze them thoroughly, discuss them with others, and approach them from different perspectives, such as through experiments or simulations, not just through mathematical calculations.

Student 2

Student 2 exhibits a keen interest in scientific subjects; however, at the outset of the activities, he believes he lacks proficiency in them and shows little inclination to modify his perspective:

> My relationship with scientific subjects was rather neutral. I found them interesting, even though I felt I lacked a natural aptitude for them, particularly in chemistry and physics.

Like student 1, he doubts his ability to conduct a hands-on experiment independently and struggles to interpret the resulting data. This clearly fixed mindset limits his willingness to step outside his comfort zone. Following participation in the TLS activities, he appears to feel slightly more confident in his abilities, but his overall mindset remains largely unchanged:

> Overall, I found all of them interesting. Seeing things in practice was engaging, even though I faced some challenges in conducting the experiments on my own, as I had never done them this way before.

He was still not sure about his ability to conduct an experiment but he found the activities engaging and appreciated the peer discussions:

> I'm not sure, I still feel quite insecure. I don't think I could conduct an experiment on my own or fully understand its results. However, discussing with my group members during the experiment was helpful,

yet he admits feeling uncomfortable speaking in front of large groups, especially during discussions, and continues to believe he lacks talent in the scientific field:

> Yes, when I had to present the results in front of all the groups, I felt a bit anxious and struggled to explain clearly what we had discussed. Honestly, I preferred when other group members took on the task of presenting the results.

He persists in the belief that he cannot surpass his limitations, indicating that he has not fully developed a growth mindset because of educational activities:

> I'm not sure if anything has really changed. I never thought I had a talent for these subjects, and I still feel the same way. It's not because of the activities we did, which were interesting, but rather because of my own perspective.

However, some improvements in the development of growth mindset can be highlighted:

> I still find scientific subjects intriguing, and maybe they no longer seem impossible to grasp, but I'm still convinced I'm not particularly good at them.

This allows us to hypothesize that greater involvement in model-based activities can further support the development of students' mindset.

Student 3

Student 3 appears to have developed a growth mindset, like student 1, despite their initial psychological profiles being quite different. At the outset, student 3 exhibited a fixed mindset, showing little openness to others or new experiences. They seemed more focused on outcomes and evaluations rather than fully comprehending the subject matter:

> I had a positive relationship with scientific subjects, though I didn't enjoy them all equally. For instance, I preferred biology over physics because I found it easier and quicker to understand.

It's worth noting that this student exuded a strong sense of self-confidence throughout the activities. After each session, they expressed a desire to know the solution to the proposed problem and exhibited some willingness towards personal reflection. However, their behavior within the group was rather domineering. They limited the other group members' freedom of expression and frequently intervened during debates with other groups:

> I found the final experiments, the quantitative ones, the most meaningful because they truly helped us understand the phenomena explored in the initial qualitative experiments. In my view, taking measurements, despite being challenging and time-consuming, is essential to ensuring the accuracy of the results. I always needed an instant solution to problems. However, thanks to my group mates, I understood that collaborating with others can greatly enhance my understanding of even the most challenging topics. I had also believed that working alone saved time, but I was just avoiding in-depth study, which led to wasted opportunities for learning. At first, when I couldn't find the answers I was looking for, I became a bit nervous. I wasn't accustomed to this new approach of gradually finding answers step by step. Initially, I didn't feel very comfortable working with others, but eventually, I came to enjoy it and found it very helpful.

By the end of the activities, student 3 mentioned that they had spent considerable time reflecting on their study approach and group interaction style. Specifically, they noted that the activities helped them to "resize" their perspective and adopt a mindset that facilitated a deeper understanding of the subjects discussed, even extending beyond the TLSs' activities:

> Yes, completely. I'm even starting to enjoy subjects I used to find more challenging, like physics. My attitude towards scientific subjects has changed a lot, depending on how I approach them. For example, I used to think that if I didn't understand something right away, I shouldn't waste time trying to figure it out, and I convinced myself that I didn't care. Now I realize that the approach was wrong. I believe that with effort, discussions with classmates, or trying different experiments, even a complex topic, not just physics, can be understood and become interesting.

DISCUSSION

Although the limited sample size prevents broad generalizations, this study offers valuable insight into how different students respond to TLSs designed to promote active engagement, metacognitive reflection, and collaborative reasoning, strictly related to growth mindset. The profiles that emerged suggest that the TLSs supported the development of growth mindset in the three students object of the study, either partially or fully, in line with what has been reported in previous literature (Stohlmann, 2022). Student 1 and student 3 appear to have developed a growth-oriented learning approach, consistent with findings by Ionescu (2020), who highlights the potential of inquiry-based strategies to shift students' implicit theories of intelligence. In both cases, participation in the TLS led students to appreciate the value of deliberate practice (Ericsson, 2007) and to recognize that academic achievement results not solely from innate ability but also from effort, strategic thinking, and persistence. Initially, both students preferred to focus on tasks they perceived as manageable and within their comfort zones. However, over the course of the TLS, they demonstrated an increased willingness to engage with complex problems, explore unfamiliar methods (e.g., computer-based simulations), and reflect on their own learning trajectories. This evolution reflects characteristics associated with metacognitive regulation and adaptive expertise, as described by Hatano and Inagaki (1986) and more recently by Yeager and Dweck (2012).

It is worth noting that student 1 highlighted a mindset change related to the use of computer-based modelling activities. In particular, he highlighted an increased confidence in his ability to understand the system evolution. This can be due to the possibility, offered by the simulation, to modify some relevant parameters and observe in real-time the results.

The case of student 3 is also significant, as it illustrates that even students who initially hold fixed-mindset beliefs can undergo meaningful shifts toward growth-mindset. His post-activity comments indicate a shift in self-perception and a willingness to adopt a more open and constructive interaction style. This aligns with research showing that metacognitive reflection (Gunstone & Mitchell, 2005) and opportunities for social negotiation (Chen & Steenhoek, 2013) can encourage students to reevaluate their assumptions and adopt more flexible learning strategies. In contrast, student 2 did not demonstrate a comparable transformation. His responses suggest that his fixed beliefs about his scientific abilities remained largely unchanged. This outcome resonates with findings from Murphy and Thomas (2008), who argue that short-term interventions may not be sufficient to impact students with deeply internalized fixed mindsets. However, it is worth noting that even this student displayed subtle behavioral improvements, such as greater willingness to participate in group discussions, despite initial discomfort. These minor shifts suggest that the TLS, while not being fully effective in modifying his epistemic beliefs, may have initiated a process of gradual engagement in making his mindset evolving. This interpretation is consistent with socio-constructivist models that view learning and identity development as iterative and context-dependent (Sinatra et al., 2015). Peer interaction played a pivotal role in shaping all three students' experiences. The structure of the TLSs, centered on laboratory exploration, model-based reasoning, and group reflection, was described as engaging and meaningful by all participants. Students emphasized how peer discussion, both in small and large group formats, encouraged them to consider alternative perspectives and deepen their understanding. These findings support previous research highlighting the importance of dialogic instruction, discourse, modelling and collaborative learning in promoting both cognitive and affective growth (Pierson & Clark, 2018; Snyder et al., 2019; Tullis & Goldstone, 2020). Indeed, the opportunity to build and discuss models, verbalize reasoning and receive feedback from peers may be especially conducive to shifting students' conceptions of intelligence from fixed to malleable. Such outcomes confirm the role of learning environments that depart from traditional, teacher-centered instruction in fostering epistemic change. As highlighted by Blackmore et al. (2011), innovative pedagogical frameworks that emphasize agency, exploration, and dialogue can transform students' engagement and self-perceptions. The TLSs examined in this study exemplify these features. By incorporating tasks that required experimentation, modelling, peer exchange, and iterative feedback, the didactic paths created affordances for both disciplinary learning and the development of productive learning dispositions. Our findings underscore the importance of carefully planned instructional design (Briggs, 1991) in supporting mindset-related change. The TLSs did not only provide access to physics content but also scaffolded students' reflective thinking and facilitated their sense of agency. These dimensions are crucial in designing learning environments that do not merely deliver content but also support students' long-term personal and academic growth (Linnenbrink-Garcia et al., 2016).

CONCLUSIONS AND IMPLICATIONS FOR PRACTICE

This study contributes to the literature on mindset development by offering a detailed, qualitative analysis of how high school students' beliefs about learning and intelligence evolve in the context of disciplinary TLSs. Unlike many previous studies that investigate mindset using self-report measures, our approach integrates interview-based thematic profiling with contextualized evidence from the students' participation in physics learning activities. This methodological triangulation allows us for a more nuanced understanding of individual learning trajectories and mindset evolution (Farrington et al., 2012). A key innovation of this work lies in the way it connects mindset theory with the design and implementation of domain-specific instruction. The TLSs were deliberately structured to elicit not only cognitive engagement but also emotional and social involvement. As students interacted with peers, manipulated models, and reflected on their learning processes, they were exposed to diverse epistemic practices that supported a more dynamic view of intelligence. This adds to the field by identifying specific instructional elements that appear to influence students' motivational and metacognitive development (Kapur, 2016).

From a practitioner's perspective, the study suggests that fostering growth mindset in science classrooms requires more than promoting effort alone. Rather, it entails providing students with structured opportunities to engage in authentic scientific inquiry, to reflect on their learning identity, and to collaborate meaningfully with others. Educators should extend and cultivate the use of model-based reasoning, computer-based modelling and simulations, hands-on experimentation, and reflective peer discussion into their instructional sequences. Importantly, these activities should be scaffolded to ensure that all students, including those with initially fixed beliefs, can participate productively and begin to revise their ability self-perceptions (Vosniadou, 2013).

Future research should investigate how such sequences can be scaled and adapted to diverse educational settings. Longitudinal studies would be particularly valuable in tracing the stability and evolution of students' epistemic beliefs over time. Additionally, quantitative validation of the emerging profiles and further exploration of the interaction between mindset, self-efficacy, and science identity could enhance our understanding of how to support all learners (Bathgate et al., 2014; Yeager et al., 2019).

In conclusion, the evidence presented here supports the claim that thoughtfully designed TLSs can promote meaningful change not only in students' conceptual understanding but also in their beliefs about learning and personal potential. By continuing to refine these approaches, educators and researchers alike can help foster resilient, reflective, and motivated learners capable of navigating the complex challenges of contemporary science education (Schraw et al., 2006).

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