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Effects on growth mindset development of a teaching/learning sequence on surface phenomena

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Effects on growth mindset development of a teaching/learning sequence on surface phenomena

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Abstract. In this paper we discuss some aspects of the design of a teaching/learning sequence (TLS) on surface phenomena for high school students, inspired by the ideas proposed by inquiry and investigative based learning approaches. A good understanding of surface phenomena is relevant in Physics and other scientific and technical fields. This, and the acknowledgement that traditional teaching methods used to introduce the basic concepts related to this topic have often proved to be not very effective in captivating students' interest and in favoring authentic understanding of the related physical content drove us in choosing this physics topic. Furthermore, some considerations on a case study on the efficacy of the TLS on the development of a growth mindset are reported.

1. Introduction

The design, implementation and validation of topic-oriented educational pathways often called Teaching-Learning Sequences (TLSs) (e.g., [1-2]) have been since some decades object of research in Science Education. A TLSs is characterized by a structure founded on research-based evolutionary processes aiming at making scientific and learner perspective interact, in order to optimize the learning outcomes and their transferability [2].

Several theoretical frameworks and teaching approaches have been proposed for designing and elaborating TLSs in the field of science education. Among the theoretical frameworks, one of the most used and discussed is the theoretical model of "Educational Reconstruction" (ER), developed by Kattmann et al. in 1995 [3-5]. The basic idea of the ER model is that teaching/learning activities should be always based on both a close analysis of science content structure and educational issues, like knowledge of the context, student common sense ideas, learning knots and processes known from research, and social and ethical implications. These two aspects, analysis of science content structure and educational issues, are equally relevant to "reconstruct" the content to be taught.

The ER model is basically founded on an integrated constructionist view: knowledge acquisition is seen as a process in which the learner plays an active role, within social and material setting, and scientific knowledge is seen as a tentative human construction [2]. As a consequence, many of the teaching approaches used for planning and developing TLSs are based on the active involvement of students in the learning activities. Research in Science Education has since long time shown that a change in teaching pedagogy from mainly deductive to approaches based on the active involvement of the learners in the construction of their knowledge can make learning significant for the learners and improve the students' understanding of concepts, longer-time knowledge retention and development of critical thinking skills (e.g., [6-8]). In the "active learning" approach students do more than just listen to a lesson. They are engaged in actively reading, writing, posing and discussing questions, gathering data from different sources, building models and in solving problems aimed at developing their knowledge, skills and attitudes.

2. Active learning

As we said, the ideas at the basis of active learning rely on the constructionist theory of learning, which describes the way people may effectively acquire knowledge and learn. Learning is a dynamic process comprising successive stages of adaption to reality during which learners actively construct knowledge by creating, testing, and reframing their theories of the world.

The literature on constructionist models of human learning, so, suggests that useable knowledge is best gained in active learning environments, which feature the following characteristics (e.g., [9]):

- provide authentic contexts that reflect the way knowledge will be used in real life
- provide authentic activities that may also be complex, ill-defined problems and investigations
- provide access to expert performances including modeling of processes
- provide multiple roles and perspectives that allow the learner to search for alternative solution pathways
- support collaborative construction of knowledge allowing for the social construction of knowledge
- promote reflection to enable abstractions to be formed and promoting metacognition
- promote articulation to enable tacit and/or common-sense knowledge to be made explicit
- provide coaching and scaffolding by the teacher at critical times
- promote the authentic assessment of learning within the tasks, that reflects the way knowledge is assessed in real life.

Many innovative approaches to science learning, like the well-known Investigative Science Learning Environment (ISLE) approach [10], also take into account that planning educational activities aimed at supporting students' motivation, self-confidence and mental growth can significantly improve the quality of learning. The ISLE approach, particularly, actively engages students in pedagogical activities mirroring scientific practice and cooperation, with the aim to develop in them deep and meaningful learning, a "growth mindset" [11], and a general sense of satisfaction in learning.

3. The growth mindset

Research results in cognitive psychology show that learning often depends on the learner's mindset [11]. Particularly, it may depend on the fact that the learner believes that his/her abilities are fixed or they can evolve and the efforts he/she puts in learning can influence that evolution. Students with a growth mindset see intelligence and skills as something that can be developed over time, while students who hold a fixed mindset tend to see them as inherent and unchangeable traits [11]. Researches on mindset allow teachers to understand how mindset fosters goals, attributions, and reactions to setbacks [12] in learning. Students who hold a growth mindset set self-improvement as achievement goals, optimize the use of their resources, look for feedback from teachers and peers. Most important, they attribute failure to something that is under their control and work harder when faced with setbacks. Students with growth mindset accept and look for possible new learning strategies and exploit all available resources. Conversely, students with a fixed mindset aim for performance-oriented goals, see failures as something that is beyond their control, and easily give up when they experience setbacks [12]. Research has shown that students who hold growth mindsets are better equipped to pursue valuable learning achievements [13]. Fostering growth mindsets can improve students' performance, increase students' motivation, and reduce social class gaps.

Students with a growth mindset are self-encouraged to put deliberate [14] and contextualized [15] effort and practice at increasing levels of complexity. In this way, they can succeed in leaving the "zone of cognitive comfort", related to things that they know they can do well, that may be unproductive from a learning point of view [16]. When students think they can improve, they put effort into things to do, like in learning activities. So, efforts, time, and support in doing things at increasing complexity levels allow students to obtain skills comparable to those of an expert, help to foster a conscious and persistent

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learning and develop self-confidence and metacognition. An important feature of deliberate practice is the exercise and active development of skills at ever higher levels, that allows students to acquire these skills in the best way [17]. Through deliberate practice processes, students can develop a personal awareness of their knowledge and skills, that allows them to better identify their strengths and weaknesses and to reflect on their learning and how to optimize it. A side effect of these procedures is that the students can also reflect on their personal learning/cognitive styles [18-20] and on the level of their learning in a given context. The aim is to help the students to develop and empower new skills and cognitive functions, avoiding spending too much time in their zone of cognitive comfort, that, as we have said, is often unfruitful to produce appreciable cognitive growth.

4. The research

4.1 Research aims

In this paper we want to describe some aspects of a wider research related to planning and pilot trialing of two TLSs on the physical concept of surface tension. This content was chosen starting from the consideration that it is related to the wide field of surface phenomena. A good understanding of these phenomena is important in physics, as well as in in other scientific and technical fields. However, very often students are introduced to the basic concepts related to this topic by means of traditional methods, based on transmissive approaches founded on macroscopic description and, at higher schooling levels, sometimes on an introduction to molecular interactions. Since many years, the research has shown that these approaches may not be completely effective in captivating student interest (e.g., [21]) and in favoring students' meaningful understanding of the physical content. For these reasons, we think it is important to propose a revised approach to the introduction of students to the study of surface phenomena, founded on an active involvement of students in laboratory and modelling activities, and also based on the implementation of models in computer simulations. Computer tools, like computer-assisted data loggers and simulations, can be very useful for students, as they can allow them to easily collect data in real-time and control parameters relevant for understanding the mechanism of functioning at the basis of the phenomena they want to study, greatly promoting model-based reasoning (e.g., [22]). Research has shown that models built at an intermediate scale (i.e., mesoscopic scale) may be effectively used in science education. In particular, mesoscopic models are recognized in the literature as useful to effectively introduce concepts like solid friction and fluid statics in educational contexts [23]. These models have the advantages of the microscopic one, but they do not require a lot of computational resources to successfully run the simulations implementing the models.

The two TLSs are both based on active learning activities founded on observation, experiments, modelling activities, small and great group discussions, etc. One TLS is developed from a macroscopic point of view, by introducing students to the general idea of cohesive and adhesive forces as responsible of surface phenomena; the other TLS is based on mesoscopic modelling of surface tension [24,25], in which the liquid is described as a set of Lagrangian particles and the interactions from which surface tension of the liquid originates are described in terms of attractive and repulsive forces. The TLSs were pilot trialed during the Academic Year 2021-22 with Upper Secondary School students and are described elsewhere [26]. The general aim of the research is to study the impact of different approaches to surface tension on students' learning. Particularly, we asked ourselves "What aspects of each approach that can be considered truly relevant in promoting an significant and persistent learning?". The idea is to use those data to formulate a new version of the TLSs that combines all the aspects that have proved to be significant in promoting student learning.

As the "promotion of student learning" is a quite complex concept to study, we conducted an extensive literature research on all the features of learning researchers focus on when they analyze this concept. We provide in Figure 1 a map of what we mean, as the result of our literature research, for "promotion of student learning" in our whole research. It is worth noting that among the most investigated features in the literature, there are perception of self-efficacy, well-being in learning, metacognition and growth mindset [27-31].

Figure 1 highlights three main aspects that may help to characterize promotion of learning in a teaching/learning sequence, with specific reference to scientific learning: acquisition of conceptual knowledge, intellectual growth, and development of a mindset fitted to learning Science. For each of these aspects, further clarification is given in the figure, so to identify the specific features, from now on called "variables", to study in the whole research.

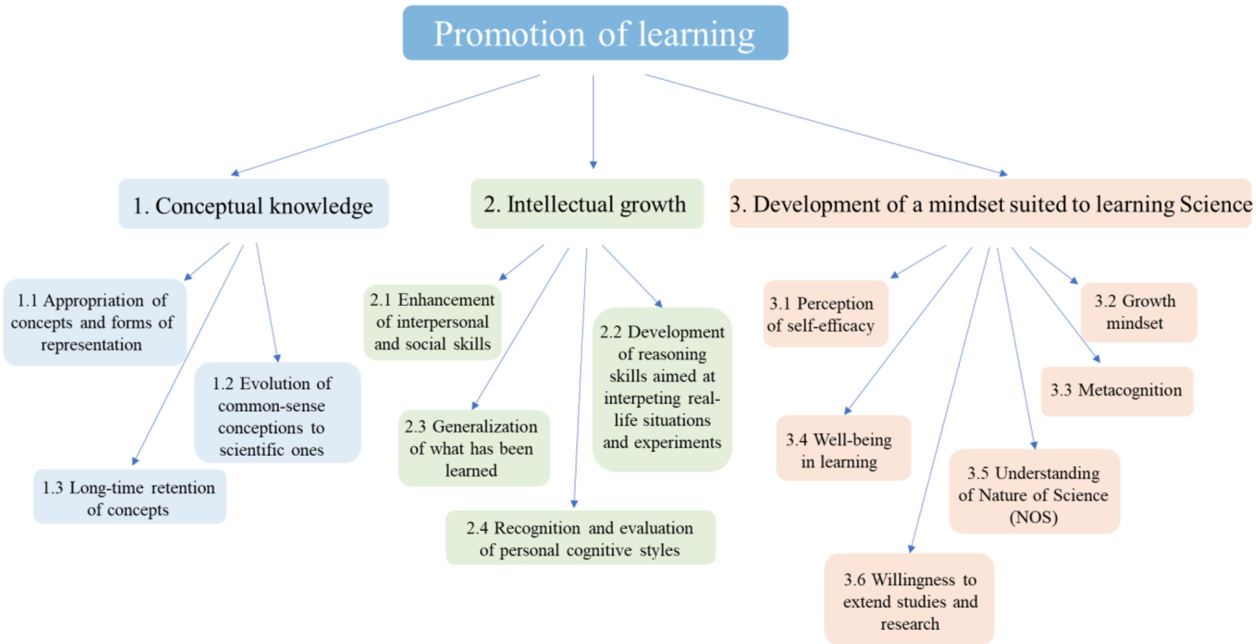

Figure 1. Diagram showing the aspects related to promoting student learning by means of the TLSs.

In this paper we discuss the interpretation of data collected to study one of the research variables: the development of growth mindset during the TLSs trialling.

4.2 The student sample

The sample on which the TLSs were experimented is made up of about 40 students attending the fourth year of "Liceo Scientifico", that is the Italian science-oriented Upper Secondary School. Students come from different classes of the same school in Palermo, Italy. Since the student sample is not very large, we selected students randomly within different classes in order to make the sample more uniform. Furthermore, since teamwork activities are an important part in our TLSs, creating working groups composed by students who do not know each other, ensures that all the students can find their place in the group and express themselves freely away from the dynamics of the class they came from. For example, the shyest students could hide behind the boldest classmates, the brightest students could "jump over" the more insecure classmates. So, before the start of the activities, this sample was randomly split into two sub-samples of about 20 students each. The first sub-sample, namely "Group A", experimented a traditional macroscopic approach to the study of surface phenomena. The second sub-sample, namely "Group B" analyzed the same topic as "Group A" but followed a mesoscopic approach.

4.3 Data collection

The data were collected by means of interviews proposed to a sub-sample of students who took part in the experimentation activities. The interviews include five questions, whose main purpose is to understand whether students have developed a growth mindset as a result of the activities carried out during the TLSs development. Originally the interview involved a sample of ten students -belonging to both groups- who impressed us for their disposition to expose themselves authentically and without filters in all the experimented contexts. In this work we focus on the answers of three students Student 1 from group B, Student 2 and Student 3 from group A) representative of three different mindset profiles. Thanks to the genuineness of the data collected we inferred interesting information on the effectiveness of the experimental activities in relation to the development of a growth mindset in students with very different starting mindset profiles.

4.4 The questionnaire

The questionnaire proposed to the students of the analyzed sample, and the responses they gave are reported in this section.

Question 1: What was your attitude towards scientific disciplines before taking part in these activities?

Student 1: "My relationship with these disciplines was good. My favorite subject was Maths. I usually succeeded in solving exercises and problems without too much difficulty. I would like to study Math at university. I was quite good also in physics or science, even if before these activities I did not think I was able to do an experiment on my own, also because I never did any on my own at school. At most, I have watched some videos showing an experiment or a professor doing it."

Student 2: "My relationship with scientific disciplines was, shall we say, neutral. Let's say I was interested in these disciplines even if I felt I did not have a talent for them, especially for chemistry and physics."

Student 3: "My relationship with scientific disciplines was positive. But I did not like them all equally. For example, I preferred biology to physics because I understand it better and faster."

Question 2: Which activities of the TLSs did you find most interesting and/or useful? Explain why.

Student 1: "I liked simulation activities. I found it interesting to follow the evolution of the system as I modified simulation parameters. The graphical representation of the system, output of the simulation, helps me to better understand what I am studying."

Student 2: "In general, all of them. It was interesting to see things in practice, even if I had some difficulty in carrying out the experiments because I had never done it like this before, by myself."

Student 3: "The final experiments, that is the quantitative ones, because in my opinion they were the ones that really made us understand the phenomena we took into account in the initial experiments, that is the qualitative ones. For me, measuring things, even if it is difficult and more time is needed, is the way to be sure of the result obtained."

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?

Student 1: "I acquired the ability to work in a group and discuss what I think with others, even when they think differently. Moreover, I realized that when carrying out an experiment, it is important to be precise and follow the correct steps to get a result that makes sense. For example, I realized that units of measurement are critical when measuring something."

Student 2: "I don't know, I still feel quite insecure. I don't think I can carry out an experiment by myself or understand the results of the experiment well. However, I found it helpful to talk to the other mates in my group while I was doing the experiment."

Student 3: "These activities made me realize that I knew much less than I thought both in terms of topics and the method of study and analysis. Before taking part in these activities, I was convinced that when you study something new, if you do not understand it immediately, you will never understand it. I thought I always had to get an immediate answer to problems. Thanks to my group mates, I realized that reasoning with others can help a lot to better understand all the topics, even the trickiest. Before these activities, I thought that working alone made me waste less time, but actually I wasted little time just because I didn't deepen what I was studying"

Question 4: Did you ever feel uncomfortable during the activities? If yes, when?

Student 1: "No, I have always felt comfortable talking with my group mates, with those of the other groups, and also with the teachers because let's say that this is also a context suitable to dialogue."

Student 2: "Yes, when I had to discuss the results in front of all the groups. I felt a little anxious and I couldn't explain well what we had discussed with my group mates. Sincerely, I preferred when the other members of the group went to discuss the results."

Student 3: "First, when I didn't have the answers I was looking for, I got a little nervous. I wasn't used to this new approach where we find answers to our questions slowly step by step. At the beginning of the activities, I didn't feel very comfortable working with other people. But then I liked it and found it very useful."

Question 5: After taking part in these TLSs, has your attitude towards scientific disciplines changed? If yes, how?

Student 1: "My attitude towards scientific disciplines is always been positive. But let's say that now I feel more confident of being able to understand even more difficult topics if I work hard to study and analyze them better, if I talk about them with others and look at them from various perspectives, such as that of experiment or simulation and not just that of mathematical calculation."

Student 2: "I don't know if it's really changed. I didn't think I had a talent for these subjects and I still think so. But not because of the activities carried out, which were interesting, but because of me. I still find interesting scientific subjects and perhaps they no longer seem impossible to understand, but I'm sure I'm not good at it."

Student 3: "Yes, completely. Now I'm also starting to like subjects that I used to find trickier, like Physics. The attitude towards scientific subjects depends a lot on how we deal with them. For example, I used to have a approach that made me believe that if I didn't understand something right away, then I didn't want to waste time figuring it out. Moreover, I convinced myself that I didn't care. Now I see that that approach was wrong. Now I think that with commitment, talking to other classmates or doing different experiments, even a complicated topic, not necessarily physics, can be understood and turns out to be interesting."

5. Discussion: students' profiles

5.1 Student 1

Student 1 shows from the beginning a positive attitude towards scientific disciplines. However, although he is interested in scientific topics and understands them readily, at the beginning of the activities he does not seem to be totally confident in tackling and solving complex topics and tasks. He is not sure to be able to carry out a hands-on experiment and finds it difficult to interpret the results obtained through

it. For these reasons, he tends to put more effort into the tasks he thinks he can do best, remaining within his comfort zone.
After taking part in the TLSs activities, his mindset starts to change. He states that one of the didactic tools he has found most useful for learning purposes is the computer-based simulation through which he has been able to follow the evolution of the analyzed physical system. Thanks to the quantitative experimental activities, he understood the importance of methodological rigor for a meaningful realization of the experiment and the interpretation of the data collected. Furthermore, the student states that he has found it useful and constructive to discuss the progress and results obtained with his peers and also with researchers, which reveals the acquisition of greater personal confidence. This student now declares he feels more confident of being able to understand even more difficult topics if he works hard to study and analyze them better and if he talks about them with others. He now looks at them from various perspectives, such as that of experiment or simulation and not just that of mathematical calculation. So, at the end of the activities he seems to have started the development of a growth mindset.

5.2 Student 2
Student 2, although quite interested in scientific disciplines, at the beginning of the activities thinks he is not good at them and does not seem inclined to change his attitude towards them. As Student 1, he does not think he can carry out a hands-on experiment on his own and finds it difficult to interpret the results obtained through it. This belief prevents him from leaving his comfort zone.
After taking part in the TLSs activities, although it seems a little more confident in his capabilities than before, his mindset does not significantly change. He found the activities carried out interesting and peer-to-peer discussions useful, but at the same time, he states that he did not feel very comfortable talking in front of a large audience (for example, during large group discussions) and he continues to think that he has no talent for scientific disciplines. He maintained the conviction of not being able to overcome his limits. This means that he has not developed a growth mindset as a result of the educational activities carried out.

5.3 Student 3
Student 3 seems to have developed a growth mindset, as Student 1, despite their starting psychological profiles being quite different. In the beginning, Student 3 presented a closed mindset, not at all inclined to be open to others and to new things. The student did not seem interested in fully understanding the topics addressed, but was instead interested in the result and in the evaluation of what was done. We note that this student has been very self-confident since the beginning of the activities. At the end of each activity, he wanted to know the answer to the problem that had been proposed and he seemed a little predisposed to personal reflection. Furthermore, his attitude within the group was quite prevaricating. He did not leave the other members of the group great freedom of expression by intervening personally in any occasion of debate with the other groups.
At the end of the activities, however, he said that he reflected a lot on his approach toward the study method and on his way of interacting in a group context. In particular, he said that the activities carried out allowed him to “resize himself” and to adopt an attitude that allowed him to understand the topics covered more deeply, even outside the TLSs’ activities.

Conclusions
Although a study performed on such a small sample of three students does not allow us to make any generalizations, it gives us some useful information on how students welcome activities based on the approach proposed in TLSs. In particular, from the answers of the students it emerges that the activities included in the TLSs have been effective in promoting the development - complete or partial - of a growth mindset.

Students 1 and 3, after taking part in experimental activities, seem to have acquired a form of growth mindset. What emerges from their answers is the awareness that deliberate practice is the key to achieving any more or less ambitious goal. Initially both students put effort only into activities in which they felt they could succeed easily. At the end of the activities, they seem ready to leave their comfort zone and face new challenges. Thanks to the achievement of the educational goals in the context of the TLSs, both students developed a greater awareness of themselves and their abilities. Both students feel they will apply and exploit what they learned during the TLSs also in other contexts.

On the other hand, at the end of the experimental activities, Student 2 has not (yet ?) acquired a growth mindset. Probably, his closed-mindset beliefs are too strong and rooted to be addressed through a few days of extracurricular activities and deserve to be addressed through a more intense and personalized educational path. Despite this, we believe that the activities carried out have had a positive impact on him. The student showed small improvements in interpersonal relationships. Even if he did not always feel comfortable, he put an increasing effort into carrying out all the activities of the educational path. This means that he has tried to step out of his comfort zone, albeit timidly.

Summing up, we believe that a TLS based on the proposed approach and structured with activities of increasing difficulty level can be effective in promoting the development of a growth mindset. In general, all the students analyzed in this case study gave positive feedback on the activities performed. In particular, they found it interesting and useful to interact with peers both in the context of a small and big group. Peer debate has taken on a key role in the path that has led students toward acquiring a growth mindset. Through discussion with peers, each student finds a way to analyze topics and deal with situations from multiple perspectives. This can help them to strengthen personal beliefs necessary for the development of a growth mindset. The introduction of alternative teaching approaches to those used in school has probably also stimulated the development of a growth mindset.

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