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Fractal Project: Effects of a Teaching Intervention on Students' Motivation for Science Learning

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Abstract
The present study aimed to examine whether student motivation changes or remains relatively stable after the completion of a teaching intervention of one school year duration focused on the study and understanding of fractals of their everyday world. There were 122 participant high school students of 10th and 11th grade. The tool used to assess student motivation before and after the teaching intervention towards learning in Science in this study, was the Students' Motivation towards Science Learning (SMTSL) questionnaire by Tuan *et al*. (2005a). It allows for six different motivational factors to be examined: Self-efficacy, active learning strategies, Science learning value, achievement goals, performance goals, and learning environment stimulation. Moreover, student motivation in three different school subjects was examined: Physics, Chemistry and Biology. The comparison of motivational factors was made between the experimental group and the control group. The findings of the statistical analyses, reveal that before the intervention the means of the motivational variables in the two groups did not differ; however, after the intervention, the motivational factors of the experimental group improved significantly in comparison to the motivational factors of the control group, which, on the contrary, decreased, with some exceptions.

Keywords: Fractals, Motivation, Physics, Chemistry, Biology, School

1. Introduction

A fundamental question that needs to be addressed by the designers and creators of the curricula for the modern school, as well as those who will implement it—teachers and educators—is the identification of the factors that will critically influence the success of the learning. The literature review shows that among the main factors that play a decisive role in the successful completion of the learning process by students, and their mastery of the conceptual change that accompanies it, lies on their motivation to learn and achieve their goals, their ability to set goals and strive to achieve them, their cognitive abilities and skills and, finally, environmental and social support (McCombs 1996; Kuhl 2000; Wolters 2003; Zusho *et al*. 2003) [40, 32, 72, 76].

A motive, according to the Cambridge Dictionary of Psychology, is '.... the hypothetical psychophysical force that motivates people to act. It is associated with the individual's desire to try to achieve the goal they have set for themselves or their actions to persuade other people to achieve goals that have been set while according to learning theories, it features any situation having reward or punishment resulting from a particular individual behavior as its goal....' (Matsumoto, p.424, 2015) [38]. In other words, motivation is the 'why' that is the reason behind human action and behaviour.

We chose the particular definition because it contains the various definitions of the derived concept of motivation that we find in the literature (Slavin 2000, Watters & Ginns 2000, Palmer 2005, Brophy 2010, Schunk Pintrich & Meece 2010, Cavaş, 2011) [58, 68, 44, 12, 56, 14] which are attributed to the different perspectives researchers examine motivation from (Atkinson 1964, Schunk Pintrich & Meece 2010, Strombach 2016).

The definition suggests that motivation is not a one-dimensional concept, but a general term that encompasses complex structures and processes (Zimmerman and Schunk 2008; Wentzel and Wigfield 2009) [75, 71]. Motivation and the resulting behaviour often determine, sometimes in both a conscious and unconscious way, people's lives, intervening decisively not only in the field of education and learning but in various fields of their lives, constituting the causes that motivate, push, deter and generally influence them to act in a positive or negative direction, justifying their actions and behaviours, finally constituting a possible valid answer to the question: What is it that causes, directs and at the same time maintains their behaviours (Kostaridou-Efklides 1999; Pintrich 2003; Ainley 2004; Dembo 2004; Başdaş 2007; Reeve 2009; Weinstein & DeHaan, 2014) [34, 52, 1, 17, 8, 53, 69]. Therefore, they constitute factors that enhance the activation level of the human body and lead it to realize the goals it has set, as they are associated with curiosity, perseverance, learning, and performance (Barlia & Beeth, 1999; Vallerandetal., 1992) [7, 66].

As far as the educational context is concerned, student pre-existing or formed during the educational process motivation, appears to contribute to the effective completion of teaching and to the achievement of learning. These effects are mainly indirect due to the fact that student motivation is linked to students' effort and to the ways in which they transfer, apply and ultimately use pre-existing knowledge, skills and strategies while simultaneously acquire and utilize new ones (Schunk Pintrich & Meece 2010) [56]. Motivation is what drives the learners to select a goal and engage with it; determines the intensity and duration of their effort, characterizes the actions they undertake, enhances their cognitive processing (Slavin 2000) [58] ultimately influencing according to Schunk Pintrich & Meece (2010, p31) [56] '...what they learn, when they learn it and how they learn it....' leading them to achieve learning. It should also be highlighted that the association shown between motivation and learning achievement is an interactional relationship and in turn high achievements can lead to increased motivation and the decision to engage with higher learning goals (Schunk Pintrich & Meece 2010) [56].

Psychological-educational research has revealed that student orientation towards learning goals, self-efficacy expectations, self-perception of their ability, their beliefs about the value of learning, but also examination-related anxiety and other emotions are important motivational factors associated with learning and teaching, directly and indirectly influencing the use of cognitive and metacognitive processes and skills (Nolen & Haladyna, 1990; Ames, 1992; Garcia 1995 [23]; Garcia & Pintrich, 1994 [22]; Pintrich & Schunk, 1996 [50]; Brophy, 1998 [11]; Hanrahan, 1998 [27]; Kuyper *et al*. 2000 [33]; Onatsu-Arvilommi *et al*. 2002 [43]; Palmer, 2005 [44]; Schraw *et al*. 2006 [55]; Yılmaz & Cavas, 2007 [74]; Cavas, 2011 [14]).

Consequently, high motivation seems to drive participants to be more attentive to the learning process and use appropriate learning strategies more frequently, resulting in higher levels of understanding and experiencing greater satisfaction and more positive emotions compared to poorly-motivated students (Onatsu-Arvilommi *et al*. 2002; Pintrich 2003; Wolters 2003; Onatsu-Arvilommi *et al*. Aunola *et al*. 2006; Zimmerman and Schunk 2008; Pekrun *et al*. 2009) [43, 52, 72, 6, 75, 47].

In conclusion, student motivation is considered to be a dynamic and changing set of factors, closely related to the learning context and the subject matter (Paris and Turner 1994; Linnenbrink and Pintrich 2002; Pintrich 2003) [45, 37, 52]. For this reason, in related research, motivational factors are usually examined within the context of specific knowledge fields/objects, such as in the field of Physics and Science, as well as their relationships with learning and learning processes in the particular field (Glynn *et al*. 2007 [25], 2009 [26]; Tuan *et al*. 2005a; Velayutham *et al*. 2011 [70], *et al*.). To this end, researchers have used specialized assessment tools to delve into primary, secondary and university student motivation in Science, and in particular in subjects such as Biology, Chemistry and Physics (Başer 2007 [9]; Juriševič *et al*. 2008 [30]; Juriševič *et al*. 2009 [31]; Tuan *et al*. 2005a). It is of exceptional interest to examine motivational factors that emerge in specific cognitive domains such as Physics, and in different cultural contexts because such studies are likely to identify similarities or differences between them (Salili *et al*. 2001; Linnenbrink and Pintrich 2002; Pintrich 2003) [54, 37, 52].

2. Motivation in the field of Science

In the context of constructivist theory, teaching and learning in Science involve interactions of cognitive processes with individual motivation (Tuan *et al*. 2005a). The cognitive component involves processing and acquisition of new concepts and content in Science, active construction of new knowledge, and the learner's own discovery of the use and application of new concepts in everyday life. Motivation, as mentioned above, refers to initiating, guiding, and maintaining learning-oriented behavior as well as learning goals.

Student motivation related to Science learning is crucial in achieving conceptual change, developing critical thinking, acquiring and using skills specific to their individual subjects, better performance levels while helping them to develop and structure both their understanding of concepts and their interconnections (Lee & Brophy, 1996; Kuyper *et al*. 2000; Velayutham *et al*. 2011; Cavas 2011) [36, 33, 70, 14].

A well-known tool for assessing motivational factors in the field of Science is the Students' Motivation Towards Science Learning (SMTSL) by Tuan *et al* (2005a). This questionnaire incorporates findings from theoretical and empirical research related to student motivation for Science learning and the factors that influence it (Lee and Brophy 1996 [36], 1998; Pintrich and Schunk 1996 [50]; Hynd *et al*. 2000 [29]), along with findings on Science learning when the underlying theory is constructivism (Pintrich *et al*. 1993; Pintrich and Schunk 1996; von Glasersfeld 1998) [49, 50, 67]. In addition, when required, its creators adapted items from previous questionnaires to create the SMTSL scales (Midgley *et al*. 2001; Pintrich *et al*. 1991) [39, 48]. Statistical evaluation of internal consistency and factorial structure suggests that the SMTSL is a reliable instrument for research purposes and can be adapted to different educational settings. The motivational components on which the instrument is based have been confirmed in research in different cultural-educational contexts (Tuan *et al*. 2005a; Dermitzaki *et al*., 2013).

Specifically, the SMTSL questionnaire includes 35 items distributed in six subscales/factors which are: Self-efficacy, use of active learning strategies, value of learning Science, performance goals, achievement goals, and stimulation of the learning environment. According to the conceptual definitions assigned by Tuan *et al*. (2005a, p. 643), '.....the *self-efficacy* scale focuses on students' beliefs about their ability to achieve good performance in Science learning tasks. The *active learning strategies* scale relates to students' active participation in constructing new knowledge through a variety of strategies based on their prior understanding. The Science learning *value* scale relates to students' perceptions of the important values associated with Science learning. The *achievement goal* scale relates to students' competition with their classroom peers and teacher attention seeking. The *learning/achievement goal* scale refers to student satisfaction associated with increased ability and achievement during Science learning. The *learning environment stimulation* scale takes into account the learning environment that influences students' motivation in Science learning.....'

Examples of studies using SMTSL are given below. Feng and Tuan (2005) [20] used the SMTSL with senior high school students as a tool to measure the change in their learning motivation after implementing specific learning activities in a Chemistry course. Tuan *et al*. (2005b) used it in examining the effect of inquiry-based instruction on student motivation for learning Science, while Chen and Yang (2006) [16] used it in investigating the effect of problem-based instruction on students' motivation for learning Science. In both studies, questionnaires were administered to students in junior high school/middle school classes. Tsai *et al*. (2007) [61] measured the differences in junior high school/middle school student motivation with regard to learning Science using the SMTSL, comparing two teaching approaches; one of which was inquiry-based and the other was textbook-based. Tseng *et al*. (2007) [62] used SMTSL to identify changes in junior high school / middle school student motivation as a possible outcome of implementing a digital type of teaching intervention. Tseng *et al*. (2010) [63] studied the relationship between conceptual change of high school students and their learning motivation concerning the 'acids, bases and salts' unit after teaching being based on an appropriately designed teaching scenario by assessing their motivation using SMTSL. Yen *et al*. (2011) [73] studied the conceptual change resulting from teaching concepts related to chemical reactions and the effect of motivation on it in junior high school/middle school students using the SMTSL to collect data on student motivation both at the beginning and throughout the teaching intervention. In addition, in a study with Greek high school students, the level of their motivation with reference to the Biology course was examined using the SMTSL. It was found that they maintained a moderate level of motivation for this subject and there were no gender differences in motivation with regard to Biology (Andressa, Mavrikaki, &Dermitzaki, 2015) [2].

Studies that document links between students' motivation to learn Science and their performance in Science courses ranging from secondary school to university will be presented will follow. For example, Tuan *et al*. (2005a) reported medium-sized (r = 0.41) and statistically significant associations of high school student motivational factors with a Science achievement test. Singh, Granville, and Dika (2002) [57] identified direct effects of motivational factors on high school student achievement in Science and Mathematics. Hynd, Holschuh, and Nist (2000) [29] found that student performance in Physics was associated with higher motivation to learn and greater interest in Physics. Yen, Tuan, and Liao (2011) [73] also reported that high school student motivation was significantly correlated with conceptual learning outcomes in two different Science-teaching contexts. Zusho *et al*. (2003) [76] suggest that in university Chemistry courses, two motivational components, namely self-efficacy and task value, were the best predictors of performance in the course. Furthermore, Glynn *et al*. (2007, 2009) [25, 26] reported that student motivation on Science, such as intrinsic motivation and self-efficacy, had a strong direct influence on their performance in Science. In a study conducted in Greece regarding primary school mathematics, student goal orientation in Mathematics influenced student self-efficacy expectations, value attributed to Mathematics, and the pleasure they experienced deriving from their engagement in Mathematics (Chatzistamatiou, Dermitzaki, Efklides, &Leondari, 2015) [15]. In turn, these three motivational factors influenced the learning strategies employed by students in Mathematics; thus, indirectly affecting their performance. Consequently, as recent studies reveal, motivating students to learn is extremely important in Science teaching and learning.

3. The present study

The present study aspires to examine whether the motivation of high school students changes or remains relatively stable over the course of a school year after the completion of a teaching intervention targeting at studying and understanding objects of their everyday world with a Fractal structure. The present study is expected to contribute with its findings to the recording of motivation factors of Greek students in the field of Science, with reference to three different high school subjects: Physics, Chemistry, and Biology. Furthermore, it will be examined whether the teaching intervention implemented was sufficient to improve student motivation in these three Science subjects over the course of a school year. Long-term data concerning student motivation with reference to three different Science subjects are not sufficiently available, not only in Greece, but also internationally.

The instrument used in this study to assess student motivation towards learning in Science is the Students' Motivation Towards Science Learning Questionnaire (SMTSL, Tuan *et al*. 2005a) which was created to be used with reference to Science. As mentioned above, the reliability and validity of this questionnaire have been successfully tested in the Greek language both with students of education departments of Greek universities and with students (Dermitzaki Stavroussi, Vavougios, Kotsis, 2013; Andressa, Mavrikaki, Dermitzaki, 2015 [2]). According to Fortus &Tuitou (2021) [21], changes in student motivation as a result of exposure to a specific teaching activity were examined not only at a given moment within the school year but at the beginning and end of a school year where the SMTSL questionnaire was administered at the beginning and end of the activity.

Based on the relevant literature, the following main research hypothesis and the following research question were formulated, as the research data available are not sufficient to formulate a second distinct hypothesis:

***Hypothesis*:** It is expected that, after the teaching intervention, the six motivation factors of the experimental group students in the three school subjects will be significantly improved compared to the motivation factors of the control group students.

***Research question*:** Does student motivation in the experimental group change in the same or in different ways in the three school subjects before and after the intervention? In other words, is there a subject in which student motivation will be affected more by the teaching intervention in comparison to the other subjects examined?

4. Methodology

Participants

The sample of this study consisted of 122 students from two schools in Greece. One hundred and seven students (107, 87.7%) came from the 1st Vocational High School of Oinoe - Schimatari of Boeotia, a fairly large Vocational High School located in an industrial zone of intense activity of whom 44 pupils attended the first grade and 63 attended the second grade. Fifteen students (15, 12.3%) came from the Junior High School & High School classes of the school unit of Pyli in Boeotia, a relatively small school in the Greek province which operates in an agricultural and farming area. Out of the total number of students participating in the study, 94 (77%) were boys and 28 (33%) were girls. There were 101 students in the Experimental Group (EG) and 21 students in the Control Group (CG).The ages of the students ranged from 15 to 17 years old; particularly for the students in Grade 1 the age range was 15 to 16 years and for the students in Grade 2 the age range was 16 to 17 years.

The Tool: Students' Motivation Towards Science Learning (Tuan et al. 2005a)

The SMTSL questionnaire developed by Tuan *et al*. (2005a) contains 35 questions, which are structured as follows: Questions 1 to 7 are about self-efficacy, questions 8 to 15 are about Active Learning Strategies, questions 16 to 20 are about Science (S) Learning value, questions 21 to 24 are about Performance Goal, questions 25 to 29 are about Achievement Goal and questions 30 to 35 are about Learning Environment Stimulation. These six subscales, as shown in Figure 1, were adapted to the Greek language and confirmed as distinct by Dermitzaki *et al*. (2013). This questionnaire was also administered to schools for the purposes of this study.

Table 2 Scales of the original SMTSL (Tuan et al., 2005a, p. 652–654), description, number of items, and example items

Scale		Description	Number of items	Example item
1.	Self-efficacy	Students' beliefs about their own ability in achieving a good performance in science learning tasks	7	Whether the science content is difficult or easy, I am sure that I can understand it
2.	Active learning strategies	Students' active participation through a variety of strategies in constructing new knowledge based on their previous understanding	8	When learning new science concepts, I attempt to understand them
3.	Science learning value	Students' perception of important values associated to science learning	5	I think that learning science is important because I can use it in my daily life
4.	Performance goal	Students' competition with peers in classroom and attention seeking from the teacher	4	I participate in science courses to get a good grade
5.	Achievement goal	Students' satisfaction related with their increased competence and achievement during science learning	5	During a science course, I feel most fulfilled when I attain a good score in a test
6.	Learning environment stimulation	Learning environment that affects the motives of students in science learning	6	I am willing to participate in this science course because the content is exciting and changeable

Picture 1: SMTS scales by Tuan *et al*. (2005a)

In order for the students to answer, a 5-point Likert type scale was employed. Students could express their opinion for every question by answering: 1. Strongly disagree, 2. Disagree, 3. Neither agree nor disagree, 4. Agree, 5. Strongly agree.

The research process

Initially, the SMTSL questionnaire was filled in during regular Physics, Chemistry and Biology classes. Participation in the research process by the students was voluntary and parental consent was additionally sought for their participation in the research process. The consent of the teachers who were teaching Physics, Chemistry and Biology at the time was also sought. In addition, the tools used were approved by the Committee of Ethics of the Department of Physics, Faculty of Sciences of the University of Thessaly.

The questionnaire was completed separately for the three subjects (Physics, Chemistry, Biology) at two different times during the school year: During the 8th week of classes, at the beginning of the school year, before the start of the teaching intervention and during the 39th week which was after the end of the intervention. The 8th week of classes was chosen because of the fact that the school classes were eventually fixed in terms of learners and the 39th week as the last week before the start of the annual in-school and national examinations. In the initial page of the questionnaire, questions regarding School, Class, Gender, the time of completion (Week 8 or Week 39) and the subject (Physics, Chemistry, Biology) were added so as to be completed by the student. The SMTSL questions were then listed without changing the wording in each sentence of the questionnaire regarding the subject being tested.

The questionnaire was completed after a briefing on the aims of the survey, which was given to both male and female students during the respective classes during which it was distributed (Physics, Chemistry, Biology). It was also important that students were clearly informed that the completion of the questionnaire was not compulsory and it was not a tool for their evaluation. Completing the questionnaire took between 15 and 20 minutes.

The teaching intervention

The teaching intervention, which was designed in the context of a doctoral thesis, aimed to bring students of the 1st and 2nd grade in contact with geometric and natural objects having fractal morphology and the properties identifying them (self-similarity, fractional dimension), and give them the opportunity to observe such objects in their surroundings. An additional aim was to familiarize them with the geometry of fractal structures and its applications to the modelling and study of highly complex physical, chemical, biological and technological structures. Aiming at understanding the relevant concepts, the intervention was applied throughout a school year.

Three different time phases were foreseen in its construction. The first phase included nine activities aimed at familiarizing the students with geometric fractal objects and their geometry as well as understanding the properties of self-similarity and escalation that characterize them.

In the second phase, which included six activities, the aim was to make students aware of the fact that there are physical, chemical, biological, meteorological, etc. systems that can be modeled with the help of Fractal geometry. They should be able to characterize objects as natural fractal through their fractional dimension by relating it to their geometric and natural characteristics. Objects of the natural world characterized by structures repeated at different scales and identify the self-similarity under change in scale presented by decoding their creation algorithm. By completing this phase, the experimental group went to the schoolyard and the surrounding areas where it was possible to observe trees, plants, clouds, rocks but also the laboratory in which objects with fractal structure were gathered and they engaged with observing them. The members of the EG had to choose an object with a fractal structure and present it highlighting both its characteristics (self-similarity and possibly dimension) and suggest a model for it. The researcher showed images through a projector in both groups asking the students to choose the ones corresponding to fractal objects, and document their view.

Throughout the third and last phase, the students learnt basic information about L-Systems and used it to create fractal structures with the help of the researcher. Starting off from Kox's curve and after understanding how to construct it, they created the curve on the computer using SCRATCH programming language. Then the control group members were asked, following the same logic, to create L-System rules and implement their own Fractal using the computer. The creation phase was optional for the control group (CG) members and only if they wanted to they chose to implement fractals. These activities were implemented in the Computer Laboratory of the schools.

In each phase the students initially worked by completing appropriately designed worksheets individually and then they could exchange opinions and discuss their views with the researcher, who catered to creating the appropriate environment, and with each other. Finally, it is worth mentioning that participation in the activities was voluntary and it was made clear to the participants that they were not the 'subject' of assessment in corresponding subjects in the school curriculum.

In conclusion, the overall effort tried to engage the participants in a learning process of active learning and development of critical and creative thinking, combining knowledge from the fields of Mathematics, Science, and Informatics. The effort of students to provide answers to real-world questions, which stimulate their interest, while satisfying their curiosity, we believe cultivates students' critical thinking, highlights their talents and finally develops their resourcefulness and creativity.

5. Results

To examine the effect of the intervention on EG students' motivation in the three academic subjects, in comparison to the CG, three respective 2 (Time) X 2 (Group) repeated measures MANOVAs with time (pre-post) as the repeated measure factor and group (experimental-control) as the between-subjects factor and the six motivational factors (self-efficacy, learning strategies, value of the subject, performance goals, achievement goals, learning environment stimulation) as dependent variables were performed on the data. The Box's M test which tests the equality of the covariance matrices of the dependent variables across groups (homogeneous) was non-significant, (p= .012), indicating homogeneity of the covariance matrices across the two groups. The overall multivariate was significant for all the three subjects: Physics, F=6.821, p=.000, η^2=.262, Chemistry, F=6.517, p=.000, η^2=.254, and Biology, F=7.372, p=.000, η^2=.278. Following the significant multivariate effects, the univariate Time X Group interactions for the dependent variables were examined. These are depicted in Tables 1, 2, and 3. In general, most of the motivation factors improved significantly in the EG. Specifically, with reference to Biology, the interaction of Time X Group was significant for all the motivational variables. In Chemistry, the Time X Group interaction was not significant only for the performance goals and, in Physics, the Time X Group interaction was not significant for the performance and achievement goals.

To further examine significant univariate interactions, independent samples t-tests were conducted between EG and CG separately pre- and post-intervention (Tables 1, 2 and 3). Overall, before the intervention, the means of the motivational variables in the two groups did not differ significantly. The exception before the intervention was the 'Environmental stimulation' factor in the physics course (Table 1). In this factor, the CG had a significantly higher score compared to the EG. However, after the intervention this pattern was reversed. After the intervention, the EG's motivation increased significantly, in contrast to the CG's motivation, which decreased significantly, with some exceptions. More specifically, the 'course value' and 'achievement goals' did not differ between the two groups after the intervention concerning Physics, while for Chemistry, 'achievement goals' did not differ between the two groups after the intervention. The EG significantly outperformed the CG in all motivational factors after the intervention in Biology.

Table 1: Physics course: Means and standard deviations of responses for each motivational subscale before and after the intervention - indices of multivariate repeated measures analyses of variance and independent samples t-tests

	Experimental Group		Control Group		Repeated measures MANOVA–Univariate Tests: Time X Team			t-tests of independent samples	
	Mean	SD	Mean	SD	F	p	partial η^2	t	p
Self-efficacy before	2.67	.84	2.90	.73	11.048	.001	.084		
Self-efficacy after	3.12	.83	2.62	.40				2.675	.009
Use of Strategies before	2.86	.90	3.28	.78	20.640	.000	.147		
Use of Strategies after	3.11	.77	2.55	.33				3.213	.002
Value before	2.69	.83	3.12	.67	17.483	.000	.127		
Value after	3.07	.85	2.58	.32					
Performance Goals before	3.49	.84	3.17	.79		μ.σ.			
Performance Goals after	3.20	.89	2.51	.54				3.410	.001
Achievement Goals before	3.05	1.01	3.35	.64		μ.σ.			
Achievement Goals after	2.94	.88	2.65	.56					
Environment stimulation before	2.55	.78	3.19	.44	37.844	.000	.240	-3.635	.000
Environment stimulation after	3.19	.75	2.41	.43				4.590	.000

p<.01, n.s.= non-significant

Table 2: Chemistry course: Means and standard deviations of responses for each motivational subscale before and after the intervention - Indicators of multivariate repeated measures analyses of variance and independent samples t-tests

	Experimental Group		Control Group		Repeated measures MANOVA - Univariate Tests: Time X Group			t-tests independent samples	
	Mean	SD	Mean	SD	F	p	partial η^2	t	p
Self-efficacy before	2.61	.66	2.80	.81	15.823	.000	.116		
Self-efficacy after	3.32	1.00	2.61	.45				3.190	.002
Use of Strategies before	2.76	.82	2.98	.78	15.660	.000	.115		
Use of Strategies after	3.31	.89	2.56	.44				3.733	.000
Value before	2.64	.81	2.93	.72	22.242	.000	.156		
Value after	3.43	.93	2.55	.49				4.177	.000
Performance Goals before	3.37	.81	3.11	.66		n.s.			
Performance Goals after	3.29	1.01	2.73	.47					
Achievement Goals before	2.98	.88	3.46	.50	22.020	.000	.155		
Achievement Goals after	3.24	.94	2.54	.61				3.240	.002
Environment stimulation before	2.57	.69	2.98	.51	31.991	.000	.210		
Environment stimulation after	3.51	.90	2.54	.49				4.777	.000

$p<.01$, n.s.= non-significant

Table 3: Biology course: Means and standard deviations of responses for each motivation subscale before and after the intervention - Indicators of multivariate repeated measures analyses of variance and independent samples t-tests

	Experimental Group		Control Group		Repeated measures MANOVA – Univariate Tests: Time X Group			t-tests independent samples	
	Mean	SD	Mean	SD	F	p	partial η^2	t	p
Self-efficacy before	3.13	.69	3.08	.58	13.504	.000	.101		
Self-efficacy after	3.77	1.17	2.68	.58				4.132	.000
Use of Strategies before	3.02	.71	3.17	.52	19.260	.000	.138		
Use of Strategies after	3.74	1.10	2.66	.59				4.334	.000
Value before	3.00	.69	3.04	.66	20.119	.000	.144		
Value after	3.82	1.17	2.57	.70				4.724	.000
Performance Goals before	3.24	.83	3.20	.67	10.434	.002	.080		
Performance Goals after	3.64	1.22	2.52	.44				4.119	.000
Achievement Goals before	3.11	.87	3.48	.62	21.927	.000	.154		
Achievement Goals after	3.70	1.17	2.58	.84				4.133	.000
Environment stimulation before	2.83	.59	3.13	.50	43.438	.000	2.66		
Environment stimulation after	3.98	1.07	2.58	.64				5.785	.000

$p<.01$, n.s.= non-significant

Furthermore, in order to examine whether the improvement in EG motivation differed significantly among the three school subjects (Physics, Chemistry, Biology), one composite motivation score was calculated for each subject by adding the scores of the six subscales and dividing it by six. This calculation was based on the STMSL structural validity test (Dermitzaki et. al., 2013) in which a second order common general motivational factor was found to explain a significant part of the variance in the six subject subscales. After calculating two general motivation scores for each school course (one before and one after the intervention), a multivariate analysis of variance with repeated measures (MANOVA) Time (2) x Course (3), with two within-subject factors (time, course) was conducted for the EG only. The six general motivational factors were the dependent variables, two for each course. Multivariate tests showed a significant overall effect of Time (2) X Course (3). More specifically, the indices were Pillai's trace F = 41.328, p = .000, η^2= .455. Overall, the analysis showed that the EG student motivation changed in different ways across the three subjects. Table 4 shows the mean and standard deviation of the overall motivation in the three subjects for the EG.

Table 4: Means and standard deviation of total pre- and post-intervention motivation in the three courses for the EG

	Experimental Group	
	Mean	SD
Motivation in Physics before	2.88	.56
Motivation in Physics after	3.11	.77
Motivation in Chemistry before	2.82	.47
Motivation in Chemistry after	3.35	.87
Motivation in Biology before	3.06	.40
Motivation in Biology after	3.78	1.08

To further explore the multivariate interaction found in the multivariate analysis of variance with repeated measures Time (2) x Course (3), we calculated a difference index for each school course by subtracting the total pre-intervention motivation grade/score from the total post-intervention motivation grade/score. Thus, for Physics, the mean difference between pre- and post-intervention motivation was .22 (Standard Deviation = .73), for Chemistry the mean difference was .53 (Standard Deviation = .82), and for Biology the mean difference was .72 (Standard Deviation = 1.04). Subsequently, three pairwise t-tests were conducted on the data, for the EG only, including all three different combinations between the mean differences among the three school subject means. Table 5 shows that the difference in change in motivation between Physics and Biology is the largest, followed by the difference between Physics and Chemistry.

Table 5: Pairwise t-tests for total EG motivation before and after the intervention for the three subjects

	Mean	SD	t	p
Difference in Motivation between Physics and Chemistry	-.30	.47	-6.420	.000
Difference in Motivation between Chemistry and Biology	-.19	.55	-3.530	.001
Difference in Motivation between Chemistry and Biology	-.50	.68	-7.301	.000

6. Discussion

The present study aimed to investigate whether high school student motivation for Science changes or remains relatively stable after the completion of a school year-long teaching intervention focused on the study and understanding of objects of their everyday world with a Fractal structure. The present study is expected to contribute to record possible changes in Greek students' motivation in Science after a teaching intervention throughout a school year, with reference to three different school subjects: Physics, Chemistry, and Biology.

The main hypothesis of the study was that after the teaching intervention, the experimental group students' motivation in the three subjects should be significantly improved in comparison to the motivation of the students in the control group. This hypothesis was confirmed based on the findings of the present study. The central finding of the study was that after the teaching intervention, overall student motivation of the experimental group improved significantly in all three subjects in comparison to the control group students' motivation. These results are in partial agreement, though in a moderate sample, with those found for secondary school students by Caballero-Garcia, & Fernandez (2019) [13] and Spandana, Rani & Devi, (2020) [59] in teaching Science subjects, Eman Fathi Jalal Gad (2021) in teaching biology subjects, and Lazarevic *et al*., (2024) [35] for teaching Physics as these particular studies follow a different perspective (they do not include a double measurement). Therefore, this finding is considered to be related to the nature of the teaching intervention, according to which the experimental group participated in teaching activities with both laboratory and digital features that are proposed to stimulate and enhance student motivation according to the relevant literature (Gagne & Deci, 2005 [24]; Hofstein & Lunetta, 2003; Tseng *et al*., 2007 [62]; Sevinç *et al*., 2011 [10]). Additionally, as students prefer not to undertake learning projects if they are optional, which resulted in non-engagement of the control group participants in the respective activities, the lack of improvement of their motivation is explained to some extent.

Nonetheless, there were also distinct findings for the six different motivational factors examined. For example, the 'performance goal' factor was found not to vary as a result of the Time x Group interaction in both Physics and Chemistry, although it did vary in Biology. This type of motivation reflects students' competitive motivation. For example, when they want to get the best grade or be the one who gets the educator's attention. While 'achievement goals', which express the students' desire to become better and learn, did not differentiate as a result of the Time X Group interaction, but solely in Physics. It should be noted that regarding achievement goals, the statement that 'participation is voluntary and without any grading impact' may have led to a decline in competition among students, since their participation had already attracted the attention of their teacher.

In addition, comparisons of the two groups (EG, CG) before and after the intervention showed that in Biology, after the intervention, the EG significantly outperformed the CG in all motivational factors. In Chemistry, only 'achievement goals' did not differ between the two groups after the intervention, while in Physics, both 'value of the course' and 'achievement goals' did not differ between the two groups after the intervention. Therefore, although generally after the intervention a significant improvement in motivation was depicted in all three subjects for the EG versus the CG, there were some exceptions.

With reference to the question of whether the EG student motivation before and after the intervention changed in the same or different ways in the three different subjects tested, the results of the analyses showed that the EG student motivation for Science changed in different ways in the three subjects. An index of difference/change in motivation before and after the intervention for each school subject revealed that the largest improvement in motivation was found with reference to Biology, then with reference to Chemistry, and finally with reference to Physics. Thus, the greatest difference in motivational change was observed between Physics and Biology, in favor of motivation for Biology. This finding can be explained by the fact that participants focused more on biological systems with a fractal structure, as the information students sought from the Internet and other available sources about systems in this category captured their interest more effectively. This was either because the information aligned more closely with their prior knowledge or resonated with their existing interests.

Overall, based on the nature of the intervention and the results of the analyses already presented, we conclude that engaging students in teaching interventions, which involve real / natural world objects and structures with fractal structure, are interdisciplinary and involve students in field, laboratory and experimental activities using computers and appropriate software tools, can significantly improve student motivation for Science. Such interdisciplinary teaching interventions appear to have an extensive positive contribution to student motivation in all three relevant subjects examined namely Biology, Chemistry, and Physics, but most of all in Biology.

In conclusion, we believe that, although further study with participation of larger samples of participants is needed, improving students' motivational factors related to Science learning can make a significant contribution to Science teaching and learning, in line with recent studies.

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