Geoscience knowledge at the end of upper-secondary school in Italy

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Abstract

Understanding geoscience issues is required to face the changes affecting our planet. In many countries, students meet geoscience within the national curricula of natural sciences, but a standard geoscience curriculum does not exist, and most teachers lack a strong geological background - a common situation worldwide. In Italy, the hydrogeologic, seismic and volcanic risks affecting the territory require citizens to be aware of geological issues. In this context, monitoring basic geoscience skills at the end of schooling is necessary. As a step in this direction, a screening tool - IMES2 or 'Individuation of Misconceptions in Earth Sciences 2' - was designed and validated through psychometric analysis, for surveying geoscience knowledge at the end of upper-secondary school. It was applied to screen 403 students enrolled in the first year of different courses at the University of Pisa (Italy) in the academic year 2020-21. The results indicate the persistence, at the end of the upper secondary school, of several misconceptions *already reported in the geoscience education literature, regarding endogenous and exogenous geological processes and the geological time.*

Keywords

Earth science curriculum, student learning, quality assessment, validity and reliability study, survey development

Résumé

Pour faire face aux changements qui affectent notre planète, il est nécessaire de comprendre les questions liées aux géosciences. Dans de nombreux pays, les étudiants rencontrent les géosciences dans le cadre des programmes nationaux de sciences naturelles, mais il n'existe pas de programme standard de géosciences et la plupart des enseignants n'ont pas de solides connaissances en géologie - une situation commune dans le monde entier. En Italie, les risques hydrogéologiques, sismiques et volcaniques qui affectent le territoire exigent que les citoyens soient sensibilisés aux questions géologiques. Dans ce contexte, il est nécessaire de contrôler les compétences géoscientifiques de base à la fin de la scolarité. Dans ce but, un outil de dépistage - IMES2 ou 'Individuation of Misconceptions in Earth Sciences 2' - a été conçu et validé par une analyse psychométrique pour évaluer les connaissances en géosciences à la fin de l'école secondaire. Il a été appliqué à 403 étudiants inscrits en première année de différents cours de l'Université de Pise (Italie) pour l'année universitaire 2020-21. Les résultats indiquent la persistance, à la fin de l'école secondaire supérieure, des misconceptions concernant les processus géologiques endogènes et exogènes et le temps géologique.

Mots-clés

programme d'études en sciences de la Terre, apprentissage des élèves, évaluation de la qualité, étude de la validité et de la fiabilité, élaboration d'une enquête

Introduction

Earth sciences are taught within Natural Sciences in all levels of Italian school from the primary to the upper-secondary school. On the other hand, it is well-documented that - in Italy as well as in all southern Europe - geosciences are generally taught by teachers without a strong geological background (Greco & Almberg, 2016; Realdon et al., 2016). Moreover, geoscience teachers do not have detailed and prescriptive national guidelines for the contents to be taught. This situation makes it particularly difficult to monitor the learning outcomes at the end of schooling, in terms of knowledge of the disciplinary contents. A similar situation has been observed across several countries (King, 2013).

Based on the above considerations, it seemed useful to design a tool for assessing geoscience knowledge at the end of secondary school and single out misconceptions or alternative conceptions (for a discussion about the different terms, see Leonard et al., 2014). A first survey (IMES-Individuation of Misconceptions in Earth Science, Pieraccioni et al., 2019) performed from 2015 to 2018 on freshmen at the University of Pisa revealed that alternative conceptions about astronomy and Earth science are pervasively present. Here we present the design and results of a survey performed in 2020-21 on 403 freshmen at University of Pisa, addressing a new set of geoscience concepts spanning the exogenous and endogenous geological processes and geological time.

Theoretical framework

Being aware of students' pre-existing mental models is important for developing constructivist approaches for more effective teaching; teachers should investigate students' ideas and find educational strategies to incorporate this information into a learning-teaching process. If not adequately considered, it is possible that alternative conceptions or misconceptions persist until the end of schooling and beyond. Just for example, Dahl et al. (2005) describe the presence of misconceptions in pre-service teachers; Shtulman & Valcarcel (2012) state that naïve theories may coexist with scientific ones also in the experts themselves, at least in a latent way.

A long and deep debate is underway about the notion of misconception and the nature and the possibility of conceptual change (Delserieys et al., 2018; Potvin, 2013; Smith et al., 1993). According to many of the cited authors, it is auspicable that educational research move on from the mere identification of student misconceptions to the understanding of the development of knowledge in different areas. On the other hand, in the geoscience field the analysis of student misconceptions has a relatively fragmented history (Guffey & Slater, 2020), started well after other disciplines faced this matter within a constructivist approach to the learning process. After the informal list in Philips (1991), most papers on this topic date after 2000 (Comins, 2003; King, 2010; Sadler et al., 2009). Moreover, most of the cited studies involved students within the educational systems of Anglo-Saxon countries, and no studies - at our knowledge - were carried out on geoscience ideas that students of Mediterranean countries express at the end of their schooling. That represents a problem, because alternative conceptions have serious implications for the Earth sciences, since their permanence prevents the comprehension of very topical issues about our planet, e.g., global warming, geological risks, renewable or non-renewable georesources (Orion, 2019).

The theoretical problem

Relatively recent qualitative research in geoscience education has uncovered many alternative conceptions about Earth, its structure and its dynamics, as well as its relations with other bodies of the Solar System (e.g., Comins, 2003; Dove, 1998; King, 2010; Sadler et al., 2009). A review of over 500 geoscience misconceptions expressed by students (from primary school to college) and teachers is reported in Francek (2013) and discussed in Cheek (2010). Besides Pieraccioni et al. (2019), the only research conducted in Italy on geoscience alternative concepts was in Bezzi and Happs (1994), revealing rooted misconceptions of Italian students about volcanism in the areas in which they lived.

Many studies have been devoted to building assessment instruments to detect the presence of misconceptions in a variety of knowledge domains, following the pioneering study of Hestenes et al. (1992). These researchers adopted the Force Concept Inventory to verify the occurrence of misconceptions in Newtonian mechanics in undergraduate students through pre and post-tests. Later, concept inventories have been developed for the same purpose in other science fields, such as biology (e.g., Anderson et al., 2002), thermodynamics (e.g., Yeo & Zadnick, 2001), astronomy (e.g., Zeilik et al., 1999), digital logic (e.g., Herman et al., 2014), chemistry (e.g., Mulford & Robinson, 2002). Libarkin and coauthors built and widely applied an assessment instrument for geoscience (Geoscience Concept Inventory; Libarkin & Anderson, 2005, 2006; see also Anderson & Libarkin, 2016; Libarkin, 2008; Libarkin et al., 2005).

The misconceptions investigated in this study may be subdivided in three groups. The first one is the most represented in literature, and is related to the endogenous forces which operate on the Earth: earthquakes can be predicted (Coleman & Soellner, 1995); earthquakes are the cause of the formation of volcanoes (Barrow & Haskins, 1996); seismic waves can move particles over long distances (Kirby, 2011); volcanoes and earthquakes both occur in warm climates (Libarkin et al., 2005); magma comes from the center of the Earth (Kirby, 2011); all volcanoes erupt violently (Fries-Gaither, 2008); all volcanoes produce lava during eruptions (King, 2008); plate margins roughly correspond to continent edges (Marques & Thompson, 1997); terrestrial plates are separated by empty space (American Association for the Advancement of Science, 1993); only the continents are moving and not the oceans (Kirby, 2011).

The second group deals with the exogenous processes: clouds are made of water vapor (Henriques, 2002); the equatorial climate depends on the equator's minor distance with respect to the Sun (Kirby, 2011) or by the high number of volcanoes near the equator (Kirby, 2011); rivers do not contribute to the modeling of the landscape (Kirby, 2011); glaciers can only move the material they contain (American Association for the Advancement of Science, 1993).

The last group is related to the geological "deep time" and the life history on the Earth: all the plants and animals that lived on Earth are fossilized (Kisiel & Ancelet, 2009); Earth and life on Earth were formed simultaneously (Trend, 2001); mankind lived at the same age as the dinosaur (Schoon, 1995).

The research questions

In this work, a survey about general geoscience understanding is performed on 403 students enrolled in the first year of University of Pisa. The research serves to answer the following questions:

1. Are the students at the end of upper-secondary school able to answer questions regarding basic Earth science concepts, and how the obtained scores correlate with students' school experience (e.g. kind of school, final mark) and self-perceived knowledge?
2. Which is the frequency of some common alternative conceptions about geosciences at the end of high school?

Methodological framework

Questionnaire development

The survey is named IMES2 (Individuation of Misconceptions in Earth Science #2) and is divided in two separate sections with a total of 27 different items:

- The first section, called "personal data", contains questions about gender, age, education (type of high school attended and final score).
- The second section forms the main core of the survey, containing questions aimed to explore the student's knowledge about Earth science and the presence of misconceptions (Appendix I). A question about the self-perceived knowledge is asked at the end of the second section.

The development of the second section of the IMES2 questionnaire was based on the following steps:

1. Identification of the concepts to be included in the survey, based on a review of scientific literature on common misconceptions in Earth science (e.g., Barnett et al., 2006; Barrow & Haskins, 1996; Boudreaux et al., 2009; Dahl et al., 2005; Francek, 2013; Fries-Gaither, 2008; Kirby, 2011; Libarkin & Anderson, 2005; Libarkin, et al., 2005).
2. Items generation: questions were drafted according to item-writing guidelines based on available literature (Bardar, 2006; Haladyna et al., 2002; Jarret et al., 2012; Libarkin, 2008) and resulting in the creation of the first version of the IMES2 questionnaire.
3. Content and construct validation (see Libarkin, 2008). The relevance, clarity, and appropriateness of the items were assessed by 7 university professors specialized in different topics of geoscience, and by 6 upper-secondary school

teachers with years of teaching experience. After modification and optimization of the items, a total of 20 questions were included in the second version of the IMES2 questionnaire.

4. Communication validity: The questionnaire was tested on 18-year-old upper-secondary school students to assess its comprehensibility. This step led to some minor revisions on the text of the questions.
5. Statistical reliability was assessed on 97 freshmen students of the Geology and Natural science bachelor's degrees in September 2020.

Population and data collection

The questionnaire was digitally submitted to students enrolled in the first year of University of Pisa bachelor's degrees. Data collection was performed between February 2021 and March 2021. The 403 surveyed students attended six different degree courses: Biological sciences, Biotechnology, Science on herbal and health products, Aerospace engineering, Philosophy, Primary teacher education.

The students had 20 minutes to answer the questionnaire. Informed consent was asked to all the participants, who voluntarily joined the survey after being assured about the anonymity of the responses. The survey was anonymously filled out only once by each volunteer, according to the current Privacy Policy and Recommendation (article 13 of the GDPR 2016/679, General Data Protection Regulation, European Regulation on the protection of personal data). In Table 1 the number of surveyed students for each degree course is reported. Table 2 presents a summary of the demographic and contextual information on the participants.

TABLE 1

Number of surveyed students for each degree course

Degree Course	Surveyed students
Biological Sciences	49
Biotechnology	61
Philosophy	104
Primary Teacher Education	55
Aerospace Engineering	105
Sciences of Herbal and Health products	29
Total	**403**

TABLE 2

Participants' demographic and contextual information (gender, upper-secondary school attended and final mark at the end of secondary school)

Gender	Frequency	Percentage
Female	230	57,1%
Male	173	42,9%
Total	**403**	

Provenance school	Frequency	Percentage
Scientific *Liceo*	203	50,4%
Technical Institute	58	14,4%
Classic *Liceo*	53	13,2%
Linguistic *Liceo*	33	8,2%
Social Sciences *Liceo*	38	9,4%
Artistic *Liceo*	4	1,0%
Vocational school	14	3,5%
Total	**403**	

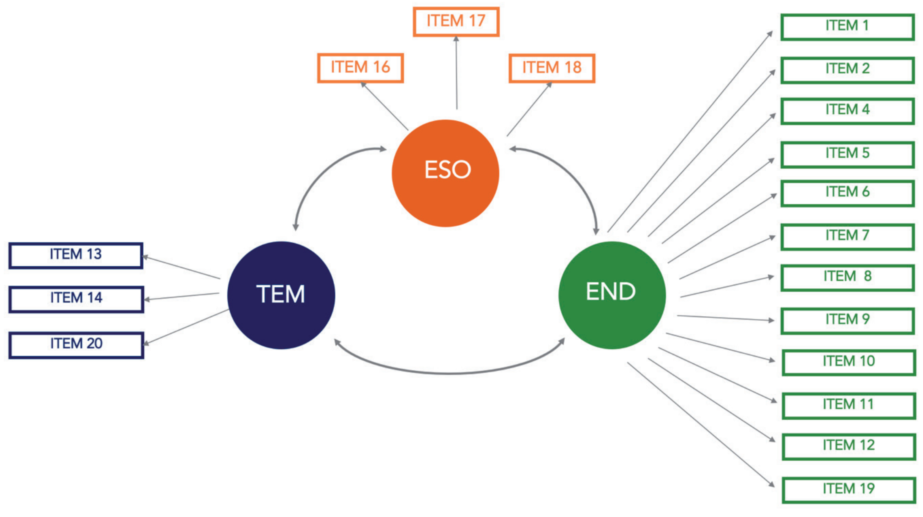
Final mark	Frequency	Percentage
60 to 69	36	8,9%
70 to 79	58	14,4%
80 to 89	69	17,1%
90 to 100	240	59,6%
Total	**403**	

Statistical analysis

All statistical analyses were completed using Stata/SE 13.1 and SPSS Version 24. Categorical variables were expressed as percentages, and continuous variables were expressed as mean and standard deviation (SD) and mean and standard error for standardized regression coefficients for the Structural Model. First, descriptive analyses were conducted to describe the sample. The level of significance was set at $p<0.05$. Three items showed $p>0.05$; two of them were discarded, resulting in the final 18 questions discussed in this paper.

Structural Equation Modeling (SEM) by Stata/SE 13.1 was used to test the proposed model (Figure 1) (Henriquez et al., 2017; Pascali et al., 2016). The path analysis technique applied measures to the extent that the model fitted a data set and allowed testing of interrelationships between a range of variables simultaneously.

FIGURE 1



Proposed model

The items were grouped into the latent variables END, ESO, and TEM. END is formed by the items regarding the endogenous Earth processes (plate tectonics, earthquakes, volcanoes), ESO groups the items regarding exogenous processes (geomorphology, atmosphere) and TEM groups items related to the geological time (age of Earth, history of Life on Earth).

The SEM was used to test an overall measurement model that included the three correlated latent variables END, ESO and TEM. Overall model fit was assessed using different statistics. First, a chi-square analysis was used. The other indices were the Root Mean Square Error of Approximation (RMSEA) (values between 0.05 and 0.08 indicate acceptable fit, and values<0.05 a good fit), Comparative Fit Index (CFI) (values>0.90 indicate reasonable fit, > 0.95 good fit), and Standardized Root Mean Square Residual (SRMR) (values<0.05 indicate good fit) (Kline, 2005). Thanks to parameter estimates extracted from the SEM model (factor loadings and residual variance), an equation was defined to compute the (rescaled) contributions to IMES2 of each component END, TEM, ESO. Subsequently, each IMES2 subscale score was rescaled to a range of 0-100, using the following formula:

$$100^{*}(\text{IMES2 subscales - min})/(\text{max - min}).$$

An analysis of the differences of IMES2 subscale scores of gender, final mark, kind of school, chosen course, and self-perceived knowledge for the different groups was performed. In this paper, the data related to education (upper secondary school and final mark) and the self-perceived knowledge are discussed.

Results

Sample and general scores

The population consists of 57% females and 43% males coming for the 50% from Scientific *liceo* and for the other 50% from six different types of high school (Table 2). Their final mark at the end of high school is in the highest range for 60% of them (Table 2).

The items in which more than 50% of the students answer correctly are 7 out of 18. The concepts tested by these questions are: the link between earthquakes, volcanoes and tectonic plates (item 1); composition, extension and speed of displacement of tectonic plates (items 8, 10); the modes of propagation of seismic waves (4); the rarity of fossilization processes and the chronology of some important events in the history of life (items 13, 20); the erosive action of rivers (item 16).

The items to which less than 25% of students answer correctly regard the composition of clouds (item 18), dating techniques (item 14) and the erosive action of glaciers (item 17).

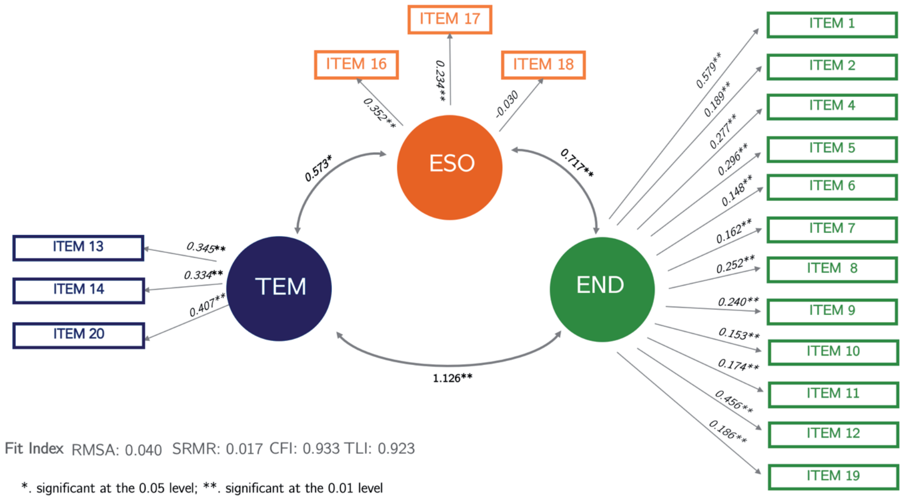
Structural Equation Model

The standardized paths of all the three components END, ESO and TEM to their respective variables were specified in Figure 1. The Structural Model Fit indices indicated that the proposed model fits the data: RMSEA=0.040, SRMR=0.017, CFI=0.933, TLI=0.923. The indices for the proposed model showed that the measurement model fits adequately (Iacobucci, 2010; Steiger, 2007).

As described in Appendix II (deposited as supplementary data), the three IMES2 components provided an acceptable explanation for their corresponding observed variables, since all the coefficients were above 0.150 (Brown, 2006), with the exception of ITEM 3 in END component, ITEM 18 in the ESO component and ITEM 15 in TEM component with a coefficient<0.150 or with p value>0.05. Standardized regression coefficients, reported to the right in Appendix II, explain the contribution of each observed variable considered as a predictor, to define the components.

In Figure 2 and in the left part of Appendix II, the weights of the three components are reported. Thus, for END, the most important predictor was ITEM 1 (Relationship between volcanoes and earthquakes to tectonic plates) (β=0.5798, SE=0.051, p<0.000) and ITEM 12 (Earth's magnetic field) (β=0.4568, SE=0.053, p<0.000); subsequently, the ESO component was strongly represented by ITEM 16 (Geomorphology, rivers) (β=0.353, SE=0.129, p< 0.006). Finally, ITEM 20 (History of Life on Earth) (β=0.4075, SE=0.065, p<0.000) was the most important predictor of TEM. The ESO component was positively associated with TEM (β=0.57364, SE=0.276, p<0.0389) and with END component (β=0.7176, SE=0.2421, p<0.003). Finally, the TEM component was positively associated with END concepts (β=1.12635, SE=0.130, p<0.000).

Figure 2



Results

The correlations of the scores with the type of school attended (Appendix III a), the final mark and the self-perceived knowledge were analyzed for the ESO, END and TEM components.

Students who attended a scientific *liceo* have better scores than students from other types of schools and in all the three components these differences are statistically significant in the comparison with vocational school, technical school, and Social Science *liceo*. In the ESO component, the better results of scientific *liceo* students are also significant with respect to linguistics *liceo*. Another statistically significant difference, found in all the components, is between the classical *liceo* and vocational school, with average better scores for the classical liceo students.

In all components (Appendix III b), there are no significant differences between the scores of the students of the two highest grade groups (90-100 and 80-89). Students in the 90-100 group perform significantly better than the lower two groups (70-79 and 60-69). Students in the 80-89 group perform significantly better than the 60-69 group.

In the END and TEM component (Appendix III c), the students who have a good self-perceived knowledge of the Earth science have on average significantly better score values than those with a sufficient or low perception and the difference is significant; in the ESO component the difference is significant only between the students with a good and those with a sufficient self-perception knowledge. The differences between the scores of the students who have sufficient and low perception are not statistically significant in all the three components.

Presence of misconceptions

In the questions answered correctly by less than 50% of the students, the answer option based on the misconception taken from the literature was preferred to the distractors in 5 out of 12 items (Table 3). In item 12 (Earth's magnetic field), the misconception (i.e., magnetic field is related to Earth's gravitational field) was chosen by 54.8% of the students. In item 11 (inner structure of Earth), 45.7% of the students answer that the center of the Earth is made up of liquid material. In Item 14 (dating methods), 78.2% of students indicate that either the analysis of fossils or carbon dating are suitable methods to know the age of the Earth. In item 18 (composition of clouds), the 91.3% answer that clouds are composed of water vapor.

TABLE 3

Frequency and percentage of misconceptions, incorrect answers, and correct answers for IMES 2 items

		misconception		**incorrect**		**correct**	
Category	Items	Count	%	Count	%	Count	%
END	Item 1 (Plate tectonics, earthquakes, volcanoes)	3	0,7%	133	33,0%	267	66,3%
	Item 2 (Earthquakes)	118	29,3%	175	43,4%	110	27,3%
	Item 4 (Earthquakes)	101	25,1%	34	8,4%	268	66,5%
	Item 5 (Earthquakes)	91	22,6%	188	46,7%	124	30,8%
	Item 6 (Volcanoes and volcanic rocks)	52	12,9%	206	51,1%	145	36,0%
	Item 7 (Volcanoes)	76	18,9%	174	43,2%	153	38,0%
	Item 8 (Plate tectonics)	70	17,4%	44	10,9%	289	71,7%
	Item 9 (Volcanoes)	36	8,9%	244	60,5%	123	30,5%
	Item 10 (Plate tectonics)	42	10,4%	117	29,0%	244	60,5%
	Item 11 (Earth' structure)	184	45,7%	96	23,8%	123	30,5%
	Item 12 (Earth's magnetic field)	221	54,8%	39	9,7%	143	35,5%
	Item 19 (Rocks)	56	13,9%	163	40,4%	184	45,7%
ESO	Item 16 (Geomorphology, rivers)	8	2,0%	52	12,9%	343	85,1%
	Item 17 (Geomorphology, glaciers)	20	5,0%	284	70,5%	99	24,6%
	Item 18 (Atmosphere)	368	91,3%	3	0,7%	32	7,9%
TEM	Item 13 (History of Life on Earth, fossilization)	11	2,7%	104	25,8%	288	71,5%
	Item 14 (Dating methods. Age of the Earth)	315	78,2%	4	1,0%	84	20,8%
	Item 20 (History of Life on Earth)	39	9,7%	158	39,2%	206	51,1%

Even among the items in which most students answer correctly, there are some cases where misconception is preferred to the distractors, in particular item 4, where 25.1% of the students answered that seismic waves propagate by moving particles or that their propagation stops at the center of the Earth.

Discussion

This study represents a first scientific attempt to address a topic not yet explored from a quantitative viewpoint in Italy. Psychometrics was applied to our data to overcome anecdotal evidences, aware that "Many conceptions that are revealed by questionnaires or interviews (...) could also have been constructed a minute ago, on the spot, for the sole purpose of satisfying the interviewer, on the simple basis of plausibility" (Potvin, 2013, p. 21). Psychometrics indicates that IMES2 is a reliable screening tool to identify strengths and critical issues in geoscience learning in Italian schools and confirms the soundness of the subdivision in three subscales, which are used for a deeper analysis of problems and observations.

Regarding the first of the two research questions, dealing with the capacity of students to answer questions regarding basic Earth science concepts, our results are multifaceted. Mean, median and mode of the score distribution is 8.0, 8 and 7, respectively, out of 18; most of the questions were answered correctly by less than 50% of the students.

With reference to the relation between the scores and the education of the students, a positive correlation between the scores and the final marks emerges for all three components. This result represents a confirmation that the selected items are related to the formal education of the students. This confirmation seems to be in agreement with the positive correlation we have observed also between the good self-perceived knowledge of the Earth science and the scores. The question about the self-perceived knowledge was general ("How do you rate your knowledge in the Earth sciences?") and not related to a specific item. Further studies could deepen the comparison between self-perception vs. the actual knowledge for each item of the questionnaire (e.g. through a Likert scale) to possibly distinguish between true misconceptions and mere lack of knowledge (Versteeg & Steendijk, 2019).

Besides, we checked the hypothesis that the overall performance of students coming from the science-oriented high school (scientific *liceo*) would be better than that of other students, based on the time dedicated to geoscience, which is longer than in the other schools. The results in Appendix III indicate that the difference between the scores of students coming from the scientific *liceo* and from the technical or vocational institutes is significant, as well as with respect to other *licei* which are oriented to humanities.

Regarding the second research question, i.e., the checking of occurrence of misconceptions at the end of schooling, our findings highlight that a large part of the Italian students at the end of the cycle of secondary instruction express misconceptions very similar to those described in the international literature for the Earth science topics. Understanding the causal factors for this outcome deserves further in-depth analysis and this kind of research could give us some interesting hints about the efficacy of the learning and teaching approaches commonly applied in Italian classrooms for geosciences.

Actually, the portrait emerging from this piece of work may stem from different causes, such as the short time devoted to Earth science, the absence of geological background of the teachers, difficulties of comprehension of complex issues, ineffective learning and teaching methods, not straightforward learning objectives. The pedagogic research, as well as the geoscience education research, showed that building a mental model of a scientific phenomenon requires time, adequate teaching strategies and a significant effort to make the model be fully understood and incorporated; in particular, learners' motivation is essential for actively changing previous naive conceptions to scientific ones.

The results of this work may stimulate further research with a more pragmatic approach to understand how one or more alternative concepts evolve in the interactions between teacher and students and among students (Delserieys et al., 2018; Santini et al., 2018).

Moreover, the awareness of the initial knowledge of first-year university students may be useful for university instructors, for example to correctly balance time devoted to reviewing fundamental concepts (Anderson & Libarkin, 2016). Finally, the conceptual understanding of the main processes involving our planet and, locally, our own territory should represent a common background for active and responsible citizenship. A tool for consistent and regular monitoring of the student knowledge in this area should be of interest for scholastic policy makers, as well as for academic and professional geology communities.

Limitations of the study

In considering the results of this study, some limitations are present. The research uses exclusively data collected in first-year university students. These, according to the Organization for Economic Co-operation and Development, in Italy represent nearly 44% of the students who finish the last year of high school. Moreover, the sample is for more than half in the upper range of final marks at the end of high school. Thus, our sample could have socio-demographic characteristics different from the general population at the end of schooling

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Appendix I

IMES2 English translation of the 20 items. The correct answers are emphasised in bold characters, whereas the alternative conceptions reported in literature are written in italics

Item	Question	Answer A	Answer B	Answer C	Answer D
#1	Which of the following sentences best summarizes the relationship that exists between volcanoes, earthquakes, and tectonic plates?	Volcanoes are usually found on islands; earthquakes occur on continents, and both occur near tectonic plates	**Volcanoes and earthquakes are usually both located along the edges of tectonic plates**	Volcanoes are usually located in the center of the tectonic plates and earthquakes usually occur along the edges of the tectonic plates	*Volcanoes and earthquakes both occur in warm climates (Libarkin, Dahl, Belifuss, & Boone, 2005)*
#2	Is it possible to predict earthquakes?	*Yes, earthquakes can be predicted (Coleman & Soellner, 1995)*	**No, earthquakes cannot be predicted**	Only in some cases can scientists predict the arrival of an earthquake	*Some animals can predict the arrival of an earthquake (USGS, 2009)*
#3	What is the relationship between earthquakes and volcanoes	*They are both caused by the pressure of the magma that builds up underground (Barrow & Haskins, 1996)*	*Earthquakes are the cause of the formation of volcanoes (Barrow & Haskins, 1996)*	They are both due to the underground heat	**Both are related to the movement of the plates**
#4	Which of the following statements regarding the seismic waves do you think is correct?	*Seismic waves can move particles over long distances (Kirby, 2011)*	*Seismic waves can propagate from the crust to the core but not from the core to the crust (Kirby, 2011)*	**Seismic waves can have different speeds**	All seismic waves can pass through any type of material
#5	An earthquake has a magnitude of 4 on the Richter scale. What is the amplitude of the oscillations detected by the seismograph for this earthquake?	100 times smaller than an earthquake of magnitude 2	*2 times smaller than an earthquake of magnitude 6 (Krishna, 1994)*	20 times smaller than an earthquake of magnitude 6	**100 times smaller than an earthquake of magnitude 6**
#6	What is the origin of the material from which volcanic rocks are formed?	*It comes from the center of the earth which contains molten material (Kirby, 2011)*	comes from a molten layer near the center of the earth	comes from a molten layer below the earth's surface	**It comes from reservoirs of molten material below the earth's surface**

#7	Which of the following statements is true?	*All volcanoes erupt violently (Fries-Gaither, 2008)*	*All volcanoes produce lava during eruptions (King, 2008)*	Most volcanoes consist of a high volcanic cone with a crater at the top	**There are volcanoes that do not produce lava during eruptions.**
#8	Which of the following statements regarding plaque margins do you think is more correct?	*Plate margins roughly correspond to continent edges (Marques & Thompson, 1997)*	*Terrestrial plates are separated by empty space (American Association for the Advancement of Science, 1993)*	**Plate edges can also be found in oceans**	Plate edges have changed only after Pangea formation
#9	The maps* shown here show the position of the oceans and continents. The black dots on each map represent the position of active volcanoes on the mainland. Which map do you think best represents the actual position of the volcanoes?	Predominantly along the edges of the Pacific and Atlantic Oceans	**Predominantly along the edges of the Pacific Ocean**	*Predominantly in warm climates (Boudreaux et al., 2009)*	*Predominantly on islands (Libarkin & Anderson, 2005)*
#10	Which of the following statements regarding plate tectonics do you consider more correct?	*Only the continents are moving and not the oceans (Kirby, 2011)*	The movement of the plates is only detectable over geological times (millions of years)	**The movement of the plates occurs at variable speeds**	*Most of the movements are due to vertical displacements (Kirby, 2011)*
#11	Which of the following sentences about the center of the Earth do you think is more correct?	The center of the Earth is mainly composed of gas	*The center of the Earth is mainly composed of liquids (Barnett et al., 2006)*	**The center of the Earth is mainly composed of solids**	Nobody knows what the state of the center is of the Earth
#12	Why does the Earth have a magnetic field?	The Earth has a crust with uneven composition	*The Earth has a gravitational attraction field (Dahl et al., 2005)*	The Earth orbits the Sun	**The Earth contains moving liquid metal**

#13	If you put all the fossils discovered in one room, would the room contain?	The fossils of most of the plants and animals that lived on Earth	**The fossils of some of the species of plants and animals that lived on Earth**	*The fossils of all the plants and animals that lived on Earth (Kisiel & Ancelet, 2009)*	The fossils of all species of plants and animals lived on Earth
#14	Which technique for determining the age of the Earth is the most accurate?	*Comparison of fossils found in rocks (Libarkin & Anderson, 2005)*	**Analysis of uranium in rocks**	*Analysis of carbon in rocks (Libarkin & Anderson, 2005)*	Scientists cannot determine the age of the Earth
#15	Why is it warmer at the equator than at the poles?	**The Earth has a spherical shape**	*The equator is closer to the Sun (Kirby, 2011)*	The Earth produces heat at the Equator	*The equator has more volcanoes (Kirby, 2011)*
#16	Which of the following statements regarding rivers do you think is more correct?	They contribute to the decrease of the water temperature of the lakes	With their contribution of water, they contribute to the rise of the sea level	**They contribute to shaping of the valleys**	*They do not contribute to the modeling of the landscape (Kirby, 2011)*
#17	What is the action of glaciers?	*They can only move the material they contain (American Association for the Advancement of Science, 1993)*	They cause erosion due to freezing and thawing processes	**They cause erosion by abrasion**	They cause erosion by corrosion
#18	What are the clouds made of?	**Clouds are made of water which can be both liquid and solid**	Clouds are made of solid-state water	*Clouds are made of water vapor (Henriques, 2002)*	*Clouds are made from dust and water vapor (Henriques, 2002)*
#19	Which of the following statements regarding rocks do you think is more correct?	The rocks that are formed when the sediments are subjected to strong pressures are sedimentary rocks.	*The rocks that are formed when the sediments are subjected to high pressure are metamorphic rocks. (King, 2010)*	**The rocks that, because of pressure and temperature variations, undergo a recrystallization of the minerals become metamorphic rocks**	Magmatic rocks are rocks which, because of changes in pressure and temperature, undergo a melting.
#20	Which of the following Figures do you think most closely represents the changes in life on Earth over time?	Fig. 1A Earth and life on Earth were formed simultaneously. (Trend, 2001)	Fig. 1B Mankind lived at the same age as the dinosaur (Schoon, 1995)		

Appendix II

Standardized factor loadings and goodness-of-fit indexes of the IMES2

Latent variables, components	Observed variables	Coeff.	Std. Err.	z	P>z	[95% CI]	
END	Item 1 (Plate tectonics, earthquakes, volcanoes)	0,579	0,051	11,17	0	0,477	0,68
	Item 2 (Earthquakes)	0,189	0,059	3,17	0,002	0,07	0,307
	Item 4 (Earthquakes)	0,277	0,058	4,73	0	0,162	0,392
	Item 5 (Earthquakes)	0,296	0,057	5,15	0	0,183	0,409
	Item 6 (Volcanoes and volcanic rocks)	0,148	0,06	2,44	0,015	0,029	0,266
	Item 7 (Volcanoes)	0,162	0,06	2,71	0,007	0,044	0,28
	Item 8 (Plate tectonics)	0,252	0,058	4,32	0	0,137	0,367
	Item 9 (Volcanoes)	0,24	0,058	4,09	0	0,125	0,355
	Item 10 (Plate tectonics)	0,153	0,06	2,56	0,011	0,035	0,271
	Item 11 (Earth' structure)	0,174	0,06	2,9	0,004	0,056	0,292
	Item 12 (Earth's magnetic field)	0,456	0,053	8,57	0	0,351	0,561
	Item 19 (Rocks)	0,186	0,06	3,1	0,002	0,068	0,304
ESO	Item 16 (Geomorphology, rivers)	0,352	0,129	2,73	0,006	0,099	0,606
	Item 17 (Geomorphology, glaciers)	0,24	0,091	2,62	0,009	0,06	0,419
	Item 18 (Atmosphere)	-0,03	0,084	-0,36	0,719	-0,196	0,135
TEM	Item 13 (History of Life on Earth, fossilization)	0,345	0,058	5,88	0	0,23	0,46
	Item 14 (Dating methods. Age of the Earth)	0,334	0,59	5,63	0	0,218	0,451
	Item 20 (History of Life on Earth)	0,407	0,064	6,29	0	0,28	0,534
ESO vs TEM		0,573	0,276	2,08	0,038	0,032	1,11
ESO vs END		0,717	0,241	2,97	0,003	0,243	1,19
TEM vs END		1,126	0,128	8,79	0	0,875	1,37
Goodness of fit indexes: Standardized Root Mean Square = 0.017, Root Mean Square error of Approximation = 0.040, Comparative Fit Index = 0.933, Tucker-Lewis index = 0.923							

Appendix III

Variance Analysis – Multiple comparisons

(a) UPPER-SECONDARY SCHOOL ATTENDED

Multiple Comparisons

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
END_ score_0_100	Vocational school	Technical school	-11,75689	5,37437	,615	-28,1907	4,6769
		Artistic Liceo	-13,61111	10,23250	1,000	-44,9002	17,6780
		Classic Liceo	-18,39007*	5,42344	,016	-34,9739	-1,8062
		Linguistic Liceo	-10,28884	5,75662	1,000	-27,8915	7,3138
		Scientific Liceo	-21,73818*	4,98721	,000	-36,9881	-6,4882
		Social Sciences Liceo	-8,68988	5,64268	1,000	-25,9441	8,5644
	Technical school	Vocational school	11,75689	5,37437	,615	-4,6769	28,1907
		Artistic Liceo	-1,85422	9,33021	1,000	-30,3842	26,6758
		Classic Liceo	-6,63318	3,42964	1,000	-17,1204	3,8540
		Linguistic Liceo	1,46805	3,93540	1,000	-10,5657	13,5018
		Scientific Liceo	-9,98129*	2,68719	,005	-18,1982	-1,7644
		Social Sciences Liceo	3,06701	3,76677	1,000	-8,4511	14,5851
	Artistic Liceo	Vocational school	13,61111	10,23250	1,000	-17,6780	44,9002
		Technical school	1,85422	9,33021	1,000	-26,6758	30,3842
		Classic Liceo	-4,77896	9,35856	1,000	-33,3957	23,8378
		Linguistic Liceo	3,32227	9,55550	1,000	-25,8967	32,5412
		Scientific Liceo	-8,12707	9,11269	1,000	-35,9920	19,7378
		Social Sciences Liceo	4,92123	9,48730	1,000	-24,0891	33,9316
	Classic Liceo	Vocational school	18,39007*	5,42344	,016	1,8062	34,9739
		Technical school	6,63318	3,42964	1,000	-3,8540	17,1204
		Artistic Liceo	4,77896	9,35856	1,000	-23,8378	33,3957
		Linguistic Liceo	8,10123	4,00215	,916	-4,1366	20,3391
		Scientific Liceo	-3,34812	2,78403	1,000	-11,8611	5,1649
		Social Sciences Liceo	9,70019	3,83646	,249	-2,0310	21,4314

	Linguistic Liceo	Vocational school	10,28884	5,75662	1,000	-7,3138	27,8915
		Technical school	-1,46805	3,93540	1,000	-13,5018	10,5657
		Artistic Liceo	-3,32227	9,55550	1,000	-32,5412	25,8967
		Classic Liceo	-8,10123	4,00215	,916	-20,3391	4,1366
		Scientific Liceo	-11,44934*	3,38759	,017	-21,8080	-1,0907
		Social Sciences Liceo	1,59896	4,29457	1,000	-11,5330	14,7310
	Scientific Liceo	Vocational school	21,73818*	4,98721	,000	6,4882	36,9881
		Technical school	9,98129*	2,68719	,005	1,7644	18,1982
		Artistic Liceo	8,12707	9,11269	1,000	-19,7378	35,9920
		Classic Liceo	3,34812	2,78403	1,000	-5,1649	11,8611
		Linguistic Liceo	11,44934*	3,38759	,017	1,0907	21,8080
		Social Sciences Liceo	13,04830*	3,19013	,001	3,2935	22,8031
	Social Sciences Liceo	Vocational school	8,68988	5,64268	1,000	-8,5644	25,9441
		Technical school	-3,06701	3,76677	1,000	-14,5851	8,4511
		Artistic Liceo	-4,92123	9,48730	1,000	-33,9316	24,0891
		Classic Liceo	-9,70019	3,83646	,249	-21,4314	2,0310
		Linguistic Liceo	-1,59896	4,29457	1,000	-14,7310	11,5330
		Scientific Liceo	-13,04830*	3,19013	,001	-22,8031	-3,2935
TEM_ score_0_100	Vocational school	Technical school	-12,65016	5,52767	,475	-29,5527	4,2524
		Artistic Liceo	-9,30564	10,52438	1,000	-41,4872	22,8759
		Classic Liceo	-20,80202*	5,57814	,005	-37,8589	-3,7451
		Linguistic Liceo	-13,67891	5,92082	,449	-31,7837	4,4259
		Scientific Liceo	-24,24280*	5,12946	,000	-39,9277	-8,5579
		Social Sciences Liceo	-8,75643	5,80363	1,000	-26,5029	8,9900
	Technical school	Vocational school	12,65016	5,52767	,475	-4,2524	29,5527
		Artistic Liceo	3,34452	9,59635	1,000	-32,6884	25,9993
		Classic Liceo	-8,15186	3,52747	,448	-18,9382	2,6345
		Linguistic Liceo	-1,02875	4,04766	1,000	-13,4057	11,3482
		Scientific Liceo	-11,59264*	2,76384	,001	-20,0439	-3,1413
		Social Sciences Liceo	3,89373	3,87422	1,000	-7,9529	15,7404

Artistic Liceo	Vocational school	9,30564	10,52438	1,000	-22,8759	41,4872
	Technical school	-3,34452	9,59635	1,000	-32,6884	25,9993
	Classic Liceo	-11,49638	9,62551	1,000	-40,9294	17,9366
	Linguistic Liceo	-4,37327	9,82807	1,000	-34,4256	25,6791
	Scientific Liceo	-14,93716	9,37263	1,000	-43,5969	13,7226
	Social Sciences Liceo	,54920	9,75792	1,000	-29,2887	30,3871
Classic Liceo	Vocational school	20,80202*	5,57814	,005	3,7451	37,8589
	Technical school	8,15186	3,52747	,448	-2,6345	18,9382
	Artistic Liceo	11,49638	9,62551	1,000	-17,9366	40,9294
	Linguistic Liceo	7,12310	4,11631	1,000	-5,4638	19,7100
	Scientific Liceo	-3,44078	2,86344	1,000	-12,1966	5,3151
	Social Sciences Liceo	12,04558	3,94589	,051	-,0202	24,1114
Linguistic Liceo	Vocational school	13,67891	5,92082	,449	-4,4259	31,7837
	Technical school	1,02875	4,04766	1,000	-11,3482	13,4057
	Artistic Liceo	4,37327	9,82807	1,000	-25,6791	34,4256
	Classic Liceo	-7,12310	4,11631	1,000	-19,7100	5,4638
	Scientific Liceo	-10,56389	3,48422	,054	-21,2180	,0902
	Social Sciences Liceo	4,92248	4,41707	1,000	-8,5841	18,4291
Scientific Liceo	Vocational school	24,24280*	5,12946	,000	8,5579	39,9277
	Technical school	11,59264*	2,76384	,001	3,1413	20,0439
	Artistic Liceo	14,93716	9,37263	1,000	-13,7226	43,5969
	Classic Liceo	3,44078	2,86344	1,000	-5,3151	12,1966
	Linguistic Liceo	10,56389	3,48422	,054	-,0902	21,2180
	Social Sciences Liceo	15,48636*	3,28113	,000	5,4533	25,5194
Social Sciences Liceo	Vocational school	8,75643	5,80363	1,000	-8,9900	26,5029
	Technical school	-3,89373	3,87422	1,000	-15,7404	7,9529
	Artistic Liceo	-,54920	9,75792	1,000	-30,3871	29,2887
	Classic Liceo	-12,04558	3,94589	,051	-24,1114	,0202
	Linguistic Liceo	-4,92248	4,41707	1,000	-18,4291	8,5841
	Scientific Liceo	-15,48636*	3,28113	,000	-25,5194	-5,4533

END_ score_0_100	Vocational school	Technical school	-12,36826	5,38126	,463	-28,8231	4,0866
		Artistic Liceo	-9,00055	10,24562	1,000	-40,3297	22,3286
		Classic Liceo	-19,93583*	5,43039	,006	-36,5409	-3,3307
		Linguistic Liceo	-13,25748	5,76400	,461	-30,8827	4,3677
		Scientific Liceo	-23,13279*	4,99360	,000	-38,4023	-7,8633
		Social Sciences Liceo	-8,76963	5,64991	1,000	-26,0460	8,5067
	Technical school	Vocational school	12,36826	5,38126	,463	-4,0866	28,8231
		Artistic Liceo	3,36771	9,34217	1,000	-25,1989	31,9343
		Classic Liceo	-7,56757	3,43404	,591	-18,0682	2,9331
		Linguistic Liceo	-,88922	3,94045	1,000	-12,9384	11,1599
		Scientific Liceo	-10,76454*	2,69063	,002	-18,9920	-2,5371
		Social Sciences Liceo	3,59863	3,77160	1,000	-7,9342	15,1315
	Artistic Liceo	Vocational school	9,00055	10,24562	1,000	-22,3286	40,3297
		Technical school	-3,36771	9,34217	1,000	-31,9343	25,1989
		Classic Liceo	-10,93528	9,37055	1,000	-39,5887	17,7181
		Linguistic Liceo	-4,25693	9,56775	1,000	-33,5133	24,9994
		Scientific Liceo	-14,13225	9,12437	1,000	-42,0329	13,7684
		Social Sciences Liceo	,23092	9,49945	1,000	-28,8166	29,2785
	Classic Liceo	Vocational school	19,93583*	5,43039	,006	3,3307	36,5409
		Technical school	7,56757	3,43404	,591	-2,9331	18,0682
		Artistic Liceo	10,93528	9,37055	1,000	-17,7181	39,5887
		Linguistic Liceo	6,67835	4,00728	1,000	-5,5752	18,9319
		Scientific Liceo	-3,19697	2,78760	1,000	-11,7209	5,3270

	Scientific Liceo	Vocational school	23,13279*	4,99360	,000	7,8633	38,4023
		Technical school	10,76454*	2,69063	,002	2,5371	18,9920
		Artistic Liceo	14,13225	9,12437	1,000	-13,7684	42,0329
		Classic Liceo	3,19697	2,78760	1,000	-5,3270	11,7209
		Linguistic Liceo	9,87531	3,39193	,080	-,4966	20,2472
		Social Sciences Liceo	14,36317*	3,19422	,000	4,5958	24,1305
	Social Sciences Liceo	Vocational school	8,76963	5,64991	1,000	-8,5067	26,0460
		Technical school	-3,59863	3,77160	1,000	-15,1315	7,9342
		Artistic Liceo	-,23092	9,49945	1,000	-29,2785	28,8166
		Classic Liceo	-11,16620	3,84138	,081	-22,9124	,5800
		Linguistic Liceo	-4,48785	4,30008	1,000	-17,6367	8,6610
		Scientific Liceo	-14,36317*	3,19422	,000	-24,1305	-4,5958

*. The mean difference is significant at the 0.05 level.

(b) FINAL MARK

Multiple Comparisons

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
ESO_ score_0_100	60 to 69	70 to 79	-4,40163	3,91489	1,000	-14,7819	5,9786
		80 to 89	-10,36244*	3,79349	,039	-20,4208	-,3041
		90 to 100	-13,02224*	3,29775	,001	-21,7662	-4,2783
	70 to 79	60 to 69	4,40163	3,91489	1,000	-5,9786	14,7819
		80 to 89	-5,96082	3,28688	,423	-14,6759	2,7543
		90 to 100	-8,62062*	2,69966	,009	-15,7787	-1,4625
	80 to 89	60 to 69	10,36244*	3,79349	,039	,3041	20,4208
		70 to 79	5,96082	3,28688	,423	-2,7543	14,6759
		90 to 100	-2,65980	2,52040	1,000	-9,3426	4,0230
	90 to 100	60 to 69	13,02224*	3,29775	,001	4,2783	21,7662
		70 to 79	8,62062*	2,69966	,009	1,4625	15,7787
		80 to 89	2,65980	2,52040	1,000	-4,0230	9,3426

TEM_ score_0_100	60 to 69	70 to 79	-4,35904	4,06797	1,000	-15,1452	6,4271
		80 to 89	-11,86449*	3,94183	,017	-22,3162	-1,4128
		90 to 100	-13,34297*	3,42670	,001	-22,4288	-4,2571
	70 to 79	60 to 69	4,35904	4,06797	1,000	-6,4271	15,1452
		80 to 89	-7,50545	3,41540	,171	-16,5613	1,5504
		90 to 100	-8,98394*	2,80522	,009	-16,4219	-1,5460
	80 to 89	60 to 69	11,86449*	3,94183	,017	1,4128	22,3162
		70 to 79	7,50545	3,41540	,171	-1,5504	16,5613
		90 to 100	-1,47849	2,61895	1,000	-8,4226	5,4656
	90 to 100	60 to 69	13,34297*	3,42670	,001	4,2571	22,4288
		70 to 79	8,98394*	2,80522	,009	1,5460	16,4219
		80 to 89	1,47849	2,61895	1,000	-5,4656	8,4226
END_ score_0_100	60 to 69	70 to 79	-4,13590	3,92246	1,000	-14,5362	6,2644
		80 to 89	-11,81507*	3,80083	,012	-21,8929	-1,7372
		90 to 100	-13,92812*	3,30413	,000	-22,6890	-5,1673
	70 to 79	60 to 69	4,13590	3,92246	1,000	-6,2644	14,5362
		80 to 89	-7,67917	3,29324	,121	-16,4111	1,0528
		90 to 100	-9,79222*	2,70488	,002	-16,9642	-2,6203
	80 to 89	60 to 69	11,81507*	3,80083	,012	1,7372	21,8929
		70 to 79	7,67917	3,29324	,121	-1,0528	16,4111
		90 to 100	-2,11305	2,52528	1,000	-8,8088	4,5827
	90 to 100	60 to 69	13,92812*	3,30413	,000	5,1673	22,6890
		70 to 79	9,79222*	2,70488	,002	2,6203	16,9642
		80 to 89	2,11305	2,52528	1,000	-4,5827	8,8088

*. The mean difference is significant at the 0.05 level.

(c) SELF-PERCEIVED KNOWLEDGE

Multiple Comparisons

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
ESO_score_0_100	Low	Sufficient	,44214	2,09425	1,000	-4,5926	5,4769
		Good	-6,55525	2,77967	,057	-13,2378	,1273
	Sufficient	Low	-,44214	2,09425	1,000	-5,4769	4,5926
		Good	-6,99739*	2,61914	,024	-13,2941	-,7007
	Good	Low	6,55525	2,77967	,057	-,1273	13,2378
		Sufficient	6,99739*	2,61914	,024	,7007	13,2941
TEM_score_0_100	Low	Sufficient	-1,08445	2,16150	1,000	-6,2809	4,1120
		Good	-9,84720*	2,86893	,002	-16,7444	-2,9500
	Sufficient	Low	1,08445	2,16150	1,000	-4,1120	6,2809
		Good	-8,76276*	2,70325	,004	-15,2616	-2,2639
	Good	Low	9,84720*	2,86893	,002	2,9500	16,7444
		Sufficient	8,76276*	2,70325	,004	2,2639	15,2616
END_score_0_100	Low	Sufficient	-,48908	2,09820	1,000	-5,5333	4,5552
		Good	-8,89522*	2,78492	,005	-15,5904	-2,2000
	Sufficient	Low	,48908	2,09820	1,000	-4,5552	5,5333
		Good	-8,40614*	2,62408	,004	-14,7147	-2,0976
	Good	Low	8,89522*	2,78492	,005	2,2000	15,5904
		Sufficient	8,40614*	2,62408	,004	2,0976	14,7147

*. The mean difference is significant at the 0.05 level.