Which geoscience knowledge at the end of upper-secondary school? Results from an Italian survey

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ABSTRACT
Monitoring basic geoscience skills at the end of upper-secondary school is necessary, when we consider that understanding geoscience issues is today required to face the changes affecting our planet. We present here the application of a screening tool - IMES2 or 'Individuation of Misconceptions in Earth Sciences 2' - designed 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 that, at the end of the upper secondary school, several misconceptions regarding endogenous and exogenous geological processes and the geological time, already reported in the geoscience education literature, are present.

KEYWORDS
Earth science curriculum, student learning, quality assessment, misconceptions, survey development

RÉSUMÉ
L*es questions liées aux géosciences sont importantes aujourd'hui, dans un planet qui change. C'est pour ça que c'est utile de monitorer 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 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, élaboration d'une enquête

INTRODUCTION

It has been documented that in Italy and, more in general, in southern Europe geosciences are mostly taught by teachers without a strong geological background (Greco & Almberg, 2016; King, 2010, 2013; Realdon, Paris, & Invernizzi, 2016). Moreover, in Italy the geoscience teachers do not have detailed and prescriptive national guidelines for the contents to be taught. Based on the above considerations, it seems useful to investigate how this situation is reflected in the geoscience knowledge of pupils at the end of secondary school, and if geoscience misconceptions or alternative conceptions are present (for a discussion about the different terms, see Leonard, Kalinowski, & Andrews, 2014). A first survey using the tool IMES, Individuation of Misconceptions in Earth Science (Pieraccioni et al., 2019) was performed from 2015 to 2018 on freshmen at the University of Pisa, revealing that alternative conceptions about astronomy and Earth science were pervasively present. A successive survey was 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 (Borghini et al. 2022). Here we will summarize the content and discuss the results of this most recent survey.

THEORETICAL FRAMEWORK

Being aware of students' pre-existing mental models is important for developing constructivist approaches for a 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, Anderson & Libarkin (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 wide literature about this topic exists (for an essential review see Borghini et al., 2022). Here we recall only that qualitative researches in geoscience education have 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; Francek, 2013; King, 2010; Sadler et al., 2009). A discussion on the results of geoscience conceptions research in the 1989-2009 period was performed by Cheek (2010). Research conducted in Italy on geoscience alternative concepts can be found in Bezzi and Happs (1994) and Pieraccioni et al. (2019), revealing rooted misconceptions of Italian students about volcanism, astronomy and other general Earth science topics.

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, Wells, & Swackhamer (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 in other science fields, such as biology (e.g., Smith, Wood, & Knight, 2008), thermodynamics (e.g., Yeo & Zadnick, 2001), astronomy (e.g., Zeilik, Schau, & Mattern, 1999), chemistry (e.g., Krause et al., 2004; Mulford & Robinson, 2002). Libarkin and coauthors built and applied an

assessment instrument for geoscience (Anderson & Libarkin, 2016; Libarkin, 2008; Libarkin & Anderson, 2005, 2006; Libarkin et al., 2005).

The research questions

In this work, the results of the survey about general geoscience understanding performed on 403 students enrolled in the first year of University of Pisa (Borghini et al., 2022) are examined 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?
2. Which alternative conceptions about geosciences are present at the end of upper-secondary school?

METHODOLOGICAL FRAMEWORK

A thorough description of the questionnaire development is reported in Borghini et al. (2022), together with the information about the surveyed sample. The questionnaire 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 (Table 1, Figures 1-2) forms the main core of the survey, containing questions aimed to explore the student's knowledge about Earth science and the presence of misconceptions**.** A question about the self-perceived knowledge is asked at the end of the second section.

TABLE 1

IMES2 English translation of the 18 items. The correct answers are emphasised in bold characters, whereas the alternative conceptions reported in the 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 et al., 2005)*
		7,2%	**66,3%**	25,8%	*0,7%*
#2	Is it possible to predict earthquakes?	*Yes, earthquakes can be predicted*	**No, earthquakes cannot be predicted**	Only in some cases can scientists predict the arrival of an earthquake	*Some animals are able to predict the arrival of an*

		(Coleman & Soellner, 1995)			*earthquake (USGS, 2009 in Francek (2013))*
		13,2%	**27,3%**	43,4%	*16,1%*
#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
		17,4%	*7,7%*	**66,5%**	8,4%
#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**
		6,7%	*22,6%*	40,0%	**30,8%**
#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**
		12,9%	13,2%	38,0%	**36,0%**
#7	Which of the following statements is true?	There are volcanoes that do not produce lava during eruptions.	*All volcanoes erupt violently (Fries-Gaither, 2008)*	*All volcanoes produce lava during eruptions (King, 2010)*	**Most volcanoes consist of a high volcanic cone with a crater at the top**
		38,0%	*1,5%*	*17,4%*	**43,2%**
#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 (AAAS Project 2061)*	**Plate edges can also be found in oceans**	Plate edges have changed only after Pangea formation
		14,4%	*3,0%*	**71,7%**	10,9%
#9	The maps shown here show the position of the	Predominantly along the edges of the Pacific	**Predominantly along the edges**	*Predominantly in warm climates*	Predominantly on islands (Libarkin &

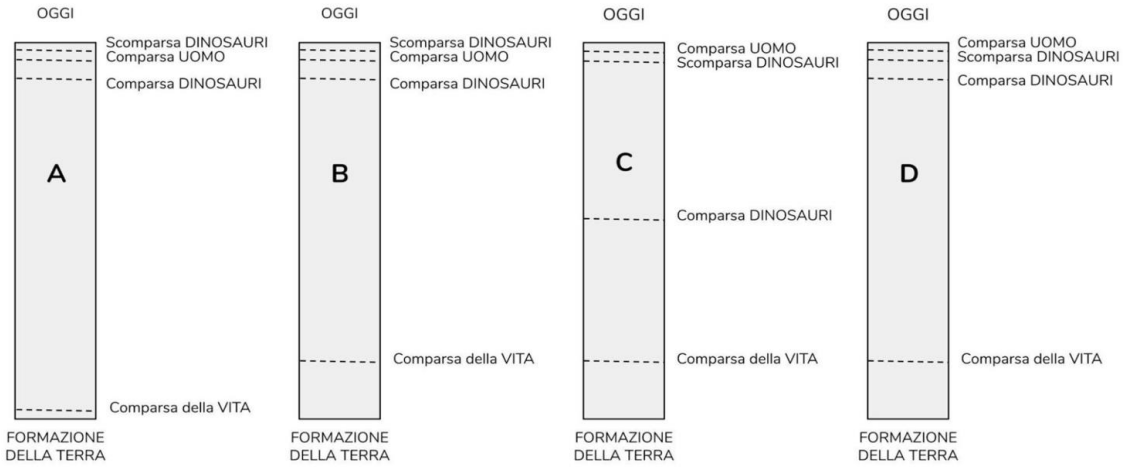
	oceans and continents (Figure 1). The black dots on each map represent the position of active volcanoes on the mainland. Which map do you think best represents the actual position of the volcanoes?	and Atlantic Oceans	**of the Pacific Ocean**	*(Boudreaux et al., 2009)*	Anderson, 2005)
		39,5%	**30,5%**	*8,9%*	21,1%
#10	Which of the following statements regarding plate tectonics do you consider more correct?	*Most of the movements are due to vertical displacements (Kirby, 2011)*	*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**
		6,2%	*4,2%*	29,0%	**60,5%**
#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
		15,9%	*45,7%*	**30,5%**	7,9%
#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**
		4,7%	*54,8%*	5,0%	**35,5%**
#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
		17,9%	**71,5%**	*2,7%*	7,9%
#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

		21,3%	**20,8%**	*56,8%*	1,0%
#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)*
		5,5%	7,4%	**85,1%**	*2,0%*
#17	What is the action of glaciers?	*They can only move the material they contain (AAAS Project 2061)*	They cause erosion due to freezing and thawing processes	**They cause erosion by abrasion**	They cause erosion by corrosion
		5,0%	64,0%	**24,6%**	6,5%
#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)*
		7,9%	0,7%	*46,7%*	*44,7%*
#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, as a consequence of pressure and temperature variations, undergo a recrystallization of the minerals become metamorphic rocks**	Magmatic rocks are rocks which, as a result of changes in pressure and temperature, undergo a melting.
		26,3%	*13,9%*	**45,7%**	14,1%
#20	Which of the following figures (Figure 2) do you think most closely represents the changes in life on Earth over time?	*Figure 2 Option A [it refers to the misconception of Planet Earth and life on Earth formed simultaneously (Trend, 2001)]*	*Figure 2 Option B [it refers to the misconception of Mankind living at the same age as the dinosaur (Schoon, 1995)]*	Figure 2 Option C	**Figure 2 Option D**
		2,7%	*6,9%*	39,2%	**51,1%**

FIGURE 1

IMES2 questionnaire: item #9 figure

FIGURE 2



IMES2 questionnaire: item #20 figure.

In the questionnaire construction the concepts to be included in the survey were selected after reviewing of scientific literature on common misconceptions in Earth science (e.g., Barnett et al., 2006; Barrow & Haskins, 1996; Dahl et al., 2005; Francek, 2013; Fries-Gaither, 2008; Kirby, 2011; Libarkin & Anderson, 2005; Libarkin et al., 2005). These misconceptions and the source references are indicated in Table 1 for each question.

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).

RESULTS

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 schools.

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).

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 2). 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 2

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

Items	misconception		incorrect		correct	
	Count	%	Count	%	Count	%
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 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 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%
Item 19 (Rocks)	56	13,9%	163	40,4%	184	45,7%
Item 20 (History of Life on Earth)	39	9,7%	158	39,2%	206	51,1%

Even among the items in which most students answered correctly, there are some cases where the misconception is preferred to the distractors. An example is 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

The misconceptions investigated in this study may be subdivided in three groups (details are given in Borghini et al. (2022); single misconceptions are reported in Table 1). The first one is the most represented in literature, and is related to the endogenous forces which operate on the Earth; the second group deals with the exogenous processes, and the last group is related to the geological "deep time" and the life history on the Earth.

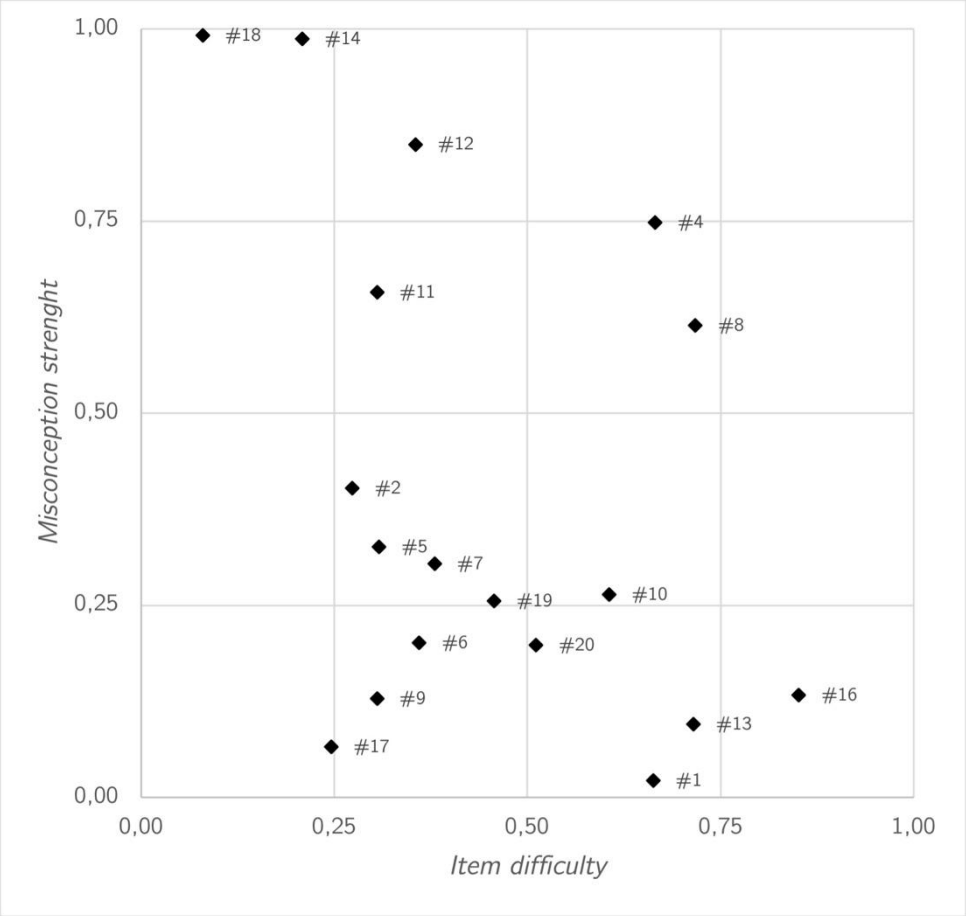
Regarding the first of the two research questions, dealing with the capacity of students to answer questions regarding basic Earth science concepts, our results are multifaceted. Mean, median and mode of the score distribution is 8.0, 8 and 7, respectively, out of 18; most of the questions were answered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

Regarding the second research question, i.e. the occurrence of misconceptions at the end of schooling, our findings highlight that a large part of the Italian students at the end of the secondary instruction expresses 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, potentially providing some interesting hints about the efficacy of the learning and teaching approaches commonly applied in Italian classrooms for geosciences.

It is worth noting that no correlation exists between the misconceptions strength and the item difficulty, as defined in Sadler et al. (2009) (Fig. 3) Misconception strength is the proportion of students that choose the misconception reported in literature out of the total number of wrong answers, and item difficulty is the proportion of students that give the correct answer. Even in low difficulty items we can have a strong misconception (e.g., item #4 and item #8), at the same time there are items with a higher difficulty (e.g., item #17) where the misconception contributes to a small part in the wrong answers.

The portrait emerging from this piece of work may stem from different causes, such as the short time devoted to Earth science teaching, the poor geological background of teachers, difficulties in comprehending 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. Understanding the evolution of one or more of these alternative concepts in the interactions between teacher and students and among students may represent a fruitful development of this research. Such a pragmatic approach was successfully adopted by several authors (Delserieys et al., 2017; Santini, Bloor, & Sensevy, 2018).

FIGURE 3



Misconception strength versus item difficulty for the IMES2 survey items. misconception strength is the proportion of students that choose the misconception reported in literature out the total number of wrong answers (Sadler et al., 2009), and item difficulty is the proportion of students that give the correct answer

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's geoscience knowledge should be of interest for scholastic policy makers, as well as for academic and professional geology communities.

In considering the results of this study, some limitations must be taken into account. 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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