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EURASIA Journal of Mathematics, Science and Technology Education, 2021, 17(4), em1950
ISSN:1305-8223 (online)
Research Paper https://doi.org/10.29333/ejmste/10780

Alternative Conceptions of Astronomy: How Irish Secondary Students Understand Gravity, Seasons, and the Big Bang

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Received 13 October 2020 ▪ Accepted 24 January 2021

Abstract

To support the development of more robust conceptual knowledge, it is crucial to understand the alternative conceptions that students bring to the classroom, and how these can be considered and dealt with through instruction. In this study, we report the alternative conceptions of 498 students enrolled in secondary education in Ireland. A quasi-experimental design elicited student ideas about gravity, seasons, and the Big Bang. Our results show 15 alternative ideas held by students across all years, which are analysed with resource framework theory to identify conceptual resources used to explain each topic. Identification of these conceptual resources provided rich information about modes of hybrid understanding where students blended formal physics concepts with daily experiences. These results could support teachers in finding new instructional approaches to address preconceived knowledge held by students, given that even senior students held the same alternative ideas as first years.

Keywords: alternative ideas, astronomy, resources framework, secondary education

INTRODUCTION

The study of our universe has inspired humankind for thousands of years (Heck, 2006). Since ancient civilisations (Krupp, 2003), humans have been working to understand our universe in great depth (Council, 2001; Leverington, 2012). As a result, over the years astronomers have developed telescopes across the many wavelengths of light to study the universe (Terebizh, 2019), contributed to everyday life technological applications derived from astronomy (Rosenberg, Baldon, Russo, & Christensen, 2014) and revolutionised the understanding of our place in the cosmos. Although astronomy has been expanding our horizons for a long time, there has been very limited inclusion content of astronomy in science curricula at secondary level. For example, only in the past 20 years was astronomy finally included as one of the mandatory subjects in the science curricula of several countries such as Brazil (de Menezes, 2004), the United Kingdom (King & Mannion, 2008), the United States (Schleigh, Slater, Slater, & Stork, 2015), Nigeria (Igbokwe, 2015) and Ireland (National Council for Curriculum and Assessment, 2015). Consequently, there are very few opportunities for professional training in astronomy teaching and learning available (Plummer & Zahm, 2010), which can result in educators with poor astronomy background knowledge (Brunsell & Marcks, 2005) and a shortage of resources for teaching the subject without reinforcing common alternative ideas.

In response to the urgent need for more research on astronomy teaching and learning in formal education (Council, 2010), a growing body of educational researchers have been investigating several aspects of astronomy education such as cognitive knowledge (Vosniadou, Skopeliti, & Ikospentaki, 2004; Vosniadou & Skopeliti, 2017), teaching materials (Taylor, Barker, & Jones, 2003), teacher education training (Korur, 2015; Turkoglu, Ornek, Gokdere, Suleymanoglu, & Orbay, 2009) and the process of conceptual change (Brewer, 2009). Schneps and Sadler (1989) produced a documentary showing that even students with high academic performance could not fully explain the reason for the seasons or the phases of the moon. The documentary highlighted that some common alternative ideas that are extremely resistant to change even after higher levels of instruction. Today, almost 20 years after that documentary was produced, students at all levels still struggle to understand basic astronomy content (Brock, Prather, & Impey, 2018; Cole, Cohen, Wilhelm, &

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Contribution to the literature

- Fifteen alternative ideas held by secondary students were identified with analysis by year group and gender, allowing a cross-sectional comparison of the ideas held by each group.
- Students' reasoning processes were explored through the resource framework. The results show that preconceived ideas can affect the process of learning, as even after instruction some of these ideas remain as the correct explanation for astronomical phenomena.
- Conceptual resources identified in this research are described in terms of their activation providing information about students' existing knowledge, the resources they have available and how those resources are organized and re-organizable in different contexts.

Lindell, 2018; Buxner, Impey, Romine, & Nieberding, 2018). However, as astronomy gains a place in formal science curricula across the world, the question remains, how can astronomical concepts be taught effectively and what makes them so difficult to understand?

Several studies (E. Slater, Morris, & McKinnon, 2018; Mills, Tomas, & Lewthwaite, 2016; S. J. Slater, 2009; Gazit, Yair, & Chen, 2005) have investigated students' conceptions about astronomical phenomena across all levels of formal education, from primary school (Stover & Saunders, 2000) to undergraduate level (Trumper, 2000), and found that even after instruction many students still performed poorly on tests of conceptual understanding. Furthermore, learners attempt to create a scientific argument by using daily experiences to explain their reasoning (Trumper, 2001a), adapting formal instruction to fit their existing knowledge structure. For example, previous studies reported that, even after instruction, it is common for secondary students to think that seasons are related to the Earth's distance to the sun (E. Slater et al., 2018) or that gravity only relates to the Earth (Kavanagh & Sneider, 2007). Thus, these alternative ideas (also referred to as misconceptions in the literature (Smith III, Disessa, & Roschelle, 1994)) are extremely resistant to change, requiring teaching approaches that encourage students to revise their initial understanding and to restructure their network of preconceived conceptions over time (Carey, 1999; Hardre, Nanny, Refai, Ling, & Slater, 2010; Kanli, 2014; Ozdemir & Clark, 2007).

It should be noted that providing detailed information about how a phenomenon occurs is not enough to promote conceptual change (National Research Council, 1997). Students must be offered opportunities to confront their current conceptions, and support in restructuring concepts based on scientific models (Ozdemir & Clark, 2007). Hence, when teaching astronomy, educators need teaching materials that encourage students to reflect on their ideas while continuously bringing new information to internalise their knowledge, supporting learners to revise their knowledge structure (Vosniadou, 2012). However, teaching for conceptual change requires educators to first be aware of students' ideas and how to incorporate them into their teaching. The ideas that students bring to the classroom must be detected through a qualitative and quantitative perspective, and used as a starting point of instruction for developing a more in-depth understanding of scientific concepts (Limón, 2001). Currently, there are very limited data about secondary students' understanding that goes beyond the correctness of the answers and how their conceptions about astronomy may change as they progress in education.

In this study, we aim to provide detailed information about Irish secondary students' prior knowledge of astronomy-related concepts and how educators can make use of these to promote conceptual change by asking:

1. What are Irish secondary students' alternative ideas about gravity, seasons and the Big Bang?
2. How does the knowledge of Irish secondary students about gravity, seasons and the Big Bang compare based on their year group?
3. What are some of the common conceptual resources that secondary students use to think about gravity, seasons and the Big Bang?

In this paper, we begin in Section *Theoretical Background* by giving a description of the previous work in astronomy understanding at secondary level as well as explaining the presence of astronomy in the Irish curriculum; Section *Methodology* describes methodology employed, outlining the study design, participants and instruments used to gather the data; Section *Results* describes the main findings, including 15 alternative ideas and 4 conceptual resources used by the students; Section *Discussion* present an analysis of our results and some limitations of this study. Finally, Section *Conclusion* summarises the main conclusions and presents future work.

THEORETICAL BACKGROUND

Astronomy in the Irish Curriculum

Inclusion of astronomy (referred to in the curriculum as Earth & Space) in the science curriculum in Ireland was a result of discussions between teachers and policy makers to increase student understanding of astronomy and our place in the universe. Since the Junior Cycle

Table 1. List of expectations for students, i.e., learning outcomes, for the Earth & Space strand in the new Junior Cycle Specification implemented in 2016 (National Council for Curriculum and Assessment, 2015)

Element	Description
Building blocks	Students should be able to: - describe the relationships between various celestial objects including moons, asteroids, comets, planets, stars, solar systems, galaxies and space - explore a scientific model to illustrate the origin of the universe - interpret data to compare the Earth with other planets and moons in the solar system, with respect to properties including mass, gravity, size, and composition.
Systems & interactions	Students should be able to: - develop and use a model of Earth-Sun-Moon system to describe predictable phenomena observable on Earth, including seasons, lunar phases, and eclipses of the Sun and the Moon - describe the cycling of matter, including that of carbon and water, associating it with biological and atmospheric phenomena.
Energy	Students should be able to: - research different energy sources; formulate and communicate an informed view of ways that current and future energy needs on Earth can be met.
Sustainability	Students should be able to: - illustrate how earth processes and human factors influence Earth's climate, evaluate effects of climate change and initiatives that attempt to address those effects - examine some of the current hazards and benefits of space exploration and discuss the future role and implications of space exploration in society.

(Gleeson, Klenowski, & Looney, 2020; Walsh, 2011) (compulsory education covering the first three years of secondary education, usually students aged between 12-15 years) was first introduced to the Irish Education system in 1989 (Department of Education and Skills, 1989), the presence of astronomy has steadily increased in the syllabus. The current version has a limited list of astronomy topics including, for example, most common daily and seasonal phenomena, and a comparison of different celestial objects (see Table 1). It should also be noted that the number of classes devoted for teaching astronomy, as well as the materials used to cover the curriculum, is not standardised in Ireland, i.e., timetabling (minimum of 40 min class required) and organisation of science subjects is at teacher and school discretion (Curriculum and Assessment Policy Unit, 2016)[1].

However, the inclusion of astronomy highlighted several problems that other science subjects also faced when they were introduced to the curriculum (McCloughlin, 2017). For instance, there is a lack of astronomy resources that could be used in formal education, due to past misalignment with the curriculum. The official website[2] for Junior Cycle science teachers only has three resources available to cover learning outcomes 2, 3 and 4. In addition, according to a recent survey conducted in 2019 by the *Irish Science Teachers Association* (ISTA), many teachers felt that there was a lack of training and materials to support the teaching of astronomy (Irish Science Teachers Association, 2019). The insufficient number of continuing professional development opportunities to support the teaching of astronomy is also not exclusive to Ireland. For instance, a study conducted by Roche, Roberts, Newsam, and Barclay (2012) in the UK revealed that, despite a large number of space-related initiatives available, teachers struggle to cover the astronomy curriculum due to issues related to "practical work or difficulties dealing with challenging concepts". Thus, although including astronomy in formal education curriculum was a major step forward, more research and support into understanding of astronomy concepts is needed in order to scaffold meaningful learning of the curriculum.

[1] Secondary education in Ireland consists of Junior Cycle (3 years), an optional Transition Year (1 year programme for students to undertake a wide range of work experience or community services, which may be optional or mandatory depending on the school policy) and a senior cycle (2 years followed by a state examination called leaving certificate). Students start secondary education at the age of 12. In 2012, an educational reform plan was proposed by the Minister for Education and Skills, Ruarí Quinn T.D., in which concerns about assessment and the amount of content were central to the development of a new framework (MacPhail, Halbert, & O'Neill, 2018; Printer, 2020). The new version of the junior cycle, in place at present, was finalised in 2015 and first implemented in autumn 2016 (National Council for Curriculum and Assessment, 2015). It set out forty-six statements of learning with no sub-topic descriptions, as well as guidelines for continuous assessment, such as classroom-based investigations, which reduced the weight of final assessment at the end of the junior cycle. The statements of the learning outcomes (LOs) are divided into five strands: The Nature of Science, Earth & Space, Chemical World, Biological World and Physical World. This was the first time that astronomy (i.e., Earth & Space strand) was included as one of the compulsory broad science areas at junior cycle level in the Irish curriculum. The Earth & Space strand in the curriculum comprises eight LOs divided into four elements: Building blocks, Systems and interactions, Energy, and Sustainability, which are described in Table 1.

[2] http://www.jct.ie/science/resources (Visited on September, 2020)

Alternative Ideas and Resources Framework

For several years, researchers have been investigating how students understand astronomy topics prior to formal instruction, which can be labelled as "preconceptions", "misconceptions", "naive theories" or "alternative ideas" (Bailey et al., 2012; Brunsell & Marcks, 2005; E. Slater et al., 2018; Gazit et al., 2005; Taylor et al., 2003; Vosniadou & Skopeliti, 2017). Tools such as mental models (Vosniadou & Skopeliti, 2017), external representation (Stover & Saunders, 2000), and visual representations (Galano et al., 2018), have been used to qualitatively explore students' underlying mechanisms to explain certain astronomy phenomena. Identifying these ideas informs educators and researchers alike about student conceptual knowledge that is not compatible with scientific explanations, and the reasons why they may be so resistant to change (Favia, Comins, & Batuski, 2016). Although this research is hugely important, it sometimes gives weight to the correctness of answers rather than the reasoning process used to generate these answers. The present study is focused on students' understanding beyond correctness, and seeks to reveal learners' prior knowledge (referred to here as "alternative ideas"), illuminating the range of ideas used to explain different astronomical phenomena. Moreover, the interpretation of students' understanding also provides information about the overlapping pieces-of-information (diSessa, 1988) which could be productively activated when describing one phenomenon, and misapplied in other contexts.

When looking at students' initial ideas, it is crucial to focus on more than just identifying common student difficulties since knowledge is a complex network with many dynamical elements (Dole & Sinatra, 1998). Constructivist researchers, such as Piaget (1955), argue that students start to build their learning from experiences with the world around them from a very early age. In this way, to enhance the learning process, students' initial ideas must be the starting point of instruction as they provide a foundation to new learning and to the development of strategies to overcome preconceived notions that could be a barrier for learning (National Research Council, 1997). According to E. Slater et al. (2018), acquisition of new knowledge is unlikely to take place when students' prior knowledge is not taken into consideration. However, to use these ideas, instructors must first be aware of them (Bailey et al., 2012). Thus, in this study, we attempted to uncover students' alternative conceptions on common astronomy topics to describe the pre-instruction knowledge that educators could encounter.

Following identification of alternative conceptions, these ideas were analyzed to identify general ideas that students used to explain the astronomy concepts. The analysis was based on the resource framework approach (Hammer, 2000), in which a resource can be defined as "an isolated, independent, productive idea that plays some role in solving a problem" (Wittmann et al., 2019, p. 536). However, the idea of knowledge-in-pieces was first introduced by diSessa (1988) in which the author further describes the phenomenological primitives (diSessa, 1993), or p-prims for short: well-structured knowledge chunks derived from personal experiences which are used to explain the world students see. Both ideas are rooted in the constructivist principle (Vygotsky, 1978a, 1978b) that knowledge is developed from experiences at an early age and affects learning development.

Furthermore, in the resources framework, each resource has some value and is neither right nor wrong; it depends on the context where the resource is applied. Hammer, Elby, Scherr, and Redish (2005) argued that resource activation depends on the context and is determined by students' views, meaning that one resource could be useful in some settings but not applicable to others. Students can make use of many or a single resource to address one problem, which allows a better understanding of students' existing knowledge and how it is organised. For example, the primitive idea of *closer means stronger* (Hammer, 2000) is correctly applied when explaining how heat is more intense closer to a fire. However, it is incorrectly activated when students use it to explain the change of seasons. From this example, we can see that resources are stable and can be applied to many situations. Thus, learning requires students not to eliminate these resources, which can serve as a seed towards a more scientific understanding, but to refine how the resources are activated and organised.

Thus, the focus of this paper is to identify students' ideas and how they are organised across all year in Junior Cycle (students aged between 12-15 years), i.e., conceptions, about different astronomical phenomena. We approached this in a two-step analysis: the first aimed at identifying students' current conceptions (prior knowledge) about astronomy; the second involved further analysing the alternative ideas through the lens of the resource framework to gain an in-depth understanding of the underlying mechanisms that students employ in their reasoning.

Students' Understanding of Astronomy

The presence of astronomy in secondary science curricula is critical to increase students' understanding of the universe. However, Diakidoy, Vosniadou, and Hawks (1997) showed that students start to develop their knowledge about astronomy at a very early age from everyday experiences, and that some concepts are very abstract, requiring a long scaffolded process to be fully understood. As a result, by the time that students move into secondary school, they can already hold several alternative conceptions about different astronomical phenomena which are very resistant to change. According to Comins (2001), astronomy has unique features (planets, stars, moons), but it relies on other science subjects, such as physics (e.g., acceleration, force, energy, displacement, time) and chemistry (e.g., chemical elements, reaction of molecules, composition of heavenly bodies), in order to be fully understood. Therefore, the process of teaching and learning astronomy can be hindered by additional challenges around students' prior knowledge of other subjects. Lightman and Sadler (1993) found that a sample of secondary students held the same alternative ideas shown by elementary school children about seasons or the phases of the Moon. The authors also showed that most educators involved in the research overestimated the improvements in conceptual knowledge after instruction. These findings are consistent with a study conducted by Kanli (2015) in which the author analysed the understanding of astronomy concepts held by physics teachers, undergraduates and secondary students. The study showed that teachers and students alike presented common alternative conceptions about a range of astronomy concepts, such as stating that a comet is a star, astrology is a scientific subject, and that stars do not rotate on an axis. (Kanli, 2015, p. 148). Moreover, Trumper (2001a, 2001b) explored junior (11-13 years) and senior (15-17 years) secondary students' knowledge of astronomy, showing that both groups have several inconsistencies in their understanding, e.g., seasons as a results of the Earth's distance to the Sun, underestimation of spatio-temporal scales of the universe, and confusion about the Sun's movement in the sky. However, the overall correct response rate was different between groups (36.4% and 43.6%, respectively).

Focusing on astronomy topics included in this study, a short description of recent research findings of secondary student knowledge of different astronomical phenomena follows below (see Table 1).

Gravity: A study carried out by Ruggiero, Cartelli, Dupre, and Vicentini-Missoni (1985) investigated 12-and 13-year-old students' understanding of the concept of gravity and factors that might affect it, such as air. The authors found that students have strongly believed that air is intimately related to gravity, and some students believed that due to the lack of atmosphere in space, weight becomes zero (Ruggiero et al., 1985). Abak, Eryilmaz, Yilmaz, and Yilmaz (2001) found that Turkish students held several misconceptions such as gravity is caused by air pressure (93%), gravity is different on different parts of the Earth (69%), and gravity is caused by rotation of Earth (81%). Moreover, Stover and Saunders (2000) showed that students have a poor understanding of how mass affects gravitational force and its effect on planetary motion. The idea of gravity as existing only on Earth was also found by Asghar and Libarkin (2010), in which half of the students involved in the research thought that gravity is only related to Earth and 93% believed that gravity is an outside force. Interestingly, Plummer et al. (2020) found that even after instruction, 46% of the students still believed that not all celestial bodies in the Solar System have gravity.

Seasons: In E. Slater et al. (2018) twelve different alternative conceptions were identified from a sample of 297 Australian students' reasoning to explain the cause of the seasons, with the most common being the Earth's varying distance from the Sun (i.e., elongated ellipse model). This finding is also consistent with Trumper (2001a) and Galano et al. (2018) in which use of the distance model to explain the change of seasons was the most common among student. Also, authors reported that some students used a "hybrid" answer in which they mix a scientific concept with an alternative conception, such as saying the Earth's tilt affects the season because it changes the distance between Australia and the Sun (E. Slater et al., 2018). Moreover, Rajpaul, Lindstrøm, Engel, Brendehaug, and Allie (2018) showed that Norwegian secondary students, even after instruction, lacked understanding about spatio-temporal scales, and the nature of basic astronomical entities.

The Big Bang: The idea that the Big Bang was an explosion has been reported in many studies (Prather, Slater, & Offerdahl, 2002; Bailey et al., 2012; Trouille et al., 2013; Aretz, Borowski, & Schmeling, 2016). Prather et al. (2002) showed nearly half the high school students associated the Big Bang with the formation of the universe. This result is consistent with the study conducted by Bailey et al. (2012) in which the vast majority of the participants believed that the Big Bang was the formation/creation of something. Also, students often assume that some matter existed before the Big Bang and that it led to the formation of our Solar System. A study by conducted by Hansson and Redfors (2006) showed that students' views of the Big Bang model could have different meanings, e.g., the absolute origin of the universe, the Big Bang as an expansion of the universe from point-like (very small), or the origin of the Earth and the Sun. Aretz et al. (2016) asked German students about pieces of evidence to support the Big Bang theory. Almost 40% of the students could not provide an answer to this question. Among those who answered, the most common answers were about the expansion of the universe and redshift. 43% of the students described the expansion as an increase in the size of the universe over time.

METHODOLOGY

This Study

In this study, we aim to report Irish students' alternative ideas about three topics included in the astronomy section of the junior cycle curriculum:

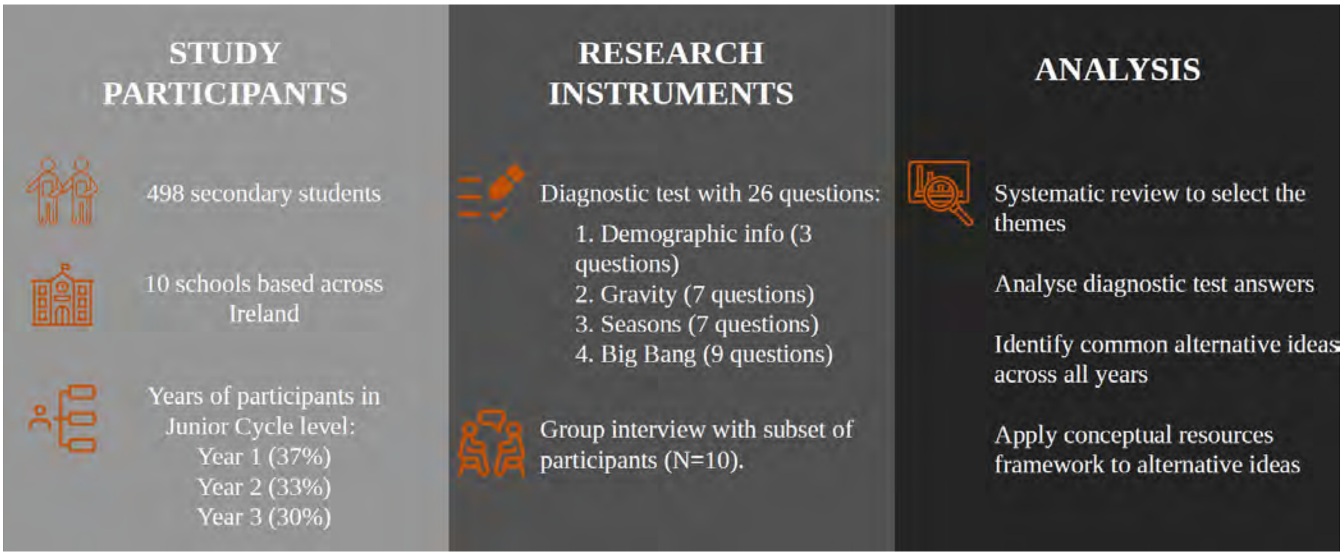

Figure 1. Graphical summary of the methodology, including the participants, data collection instruments and analysis process

gravity, seasons and The Big Bang. A survey was administered to 498 Irish secondary students currently enrolled in Junior Cycle level. Following the survey, interviews were conducted with a smaller set of students (*N* = 10) to consolidate the results (interview protocol is available on Cardinot & Fairfield (2020b)). Participation in the study was voluntary and required a signed consent form from parents, students and teachers, in accordance with ethics guidelines established by the authors' university. The anonymity of the participants was assured at all stages by removing all potentially identifiable information.

The research design follows a mixed-method approach in which both qualitative and quantitative data were collected. Quantitative data included information about demographics, statistical comparison of test scores, and factor analysis that provided information about variable relationships by collapsing a large number of variables into fewer fundamental underlying factors. Qualitative data were used to explore test scores further and to provide more details about the patterns of students' alternative ideas revealed in the study. Figure 1 presents a summary of the research design employed in this paper.

Instruments

Research instruments used in this research went through a rigorous process of validation and reliability (Cronbach's a = .72) which involved several iterations among the authors and external evaluators to revise and refine all material used to collect and analyse data. With regards to the validation, the process included conversations with external experts to establish the interpretation of students' responses and interviews with students to clarify the meaning of their answers. In order to construct validity, authors involved a large sample of students which included representatives of all Junior Cycle years. In addition, administration of the test and interviews occurred in two cycles followed by extensive statistical analysis of the responses, including a detailed factor analysis to create and verify categories of students' answers, predictive validity to identify the likelihood that a particular student (by means of the Junior Cycle year group) would have to hold an alternative idea, and concurrent validity to verify how the results obtained compare to the previous studies. Revisions were made to the instruments based on the results of the interviews and factor analysis after the first cycle. Then the above validation processes were repeated with the revised version of the test (*RMSEA* = .04).

All items included in the diagnostic test were based on previous literature on alternative ideas about seasons, gravity and the Big Bang to ensure content validity (see Section *Students' understanding of astronomy*). By using previously validated and reliable scales to measure students' ideas, the picture of the knowledge students had about astronomy should be both accurate and comparable to other datasets in the literature. The use of both qualitative (interviews) and quantitative (knowledge test) methods ensured internal consistency and external validity through a triangulation process involving two sources of data, independent researchers through the analysis process, and two data collection techniques (Cohen, Manion, & Morrison, 2013). Transferability is established by the provision of the research instruments to facilitate other researchers to replicate the findings presented in this research. Content validity of the research instruments is supported by the number of items included in the final version of the knowledge test. In particular, the knowledge test has a representative number of the central ideas to each concept helping to build confidence in the generalisation of our findings, for example, multiple questions related to distance for the seasons, explosion model for the Big Bang and gravity in motion within and outside atmosphere for the concept of gravity.

The existing students' ideas about astronomy were collected by using a written diagnostic test. The test contained 26 questions adapted from previous studies on common alternative astronomy conceptions at secondary level (Aretz et al., 2016; Bailey et al., 2012; Bar, Brosh, & Sneider, 2016; K. E. Williamson & Willoughby, 2012; Keeley & Sneider, 2012; Prather et al., 2002; Trumper, 2001a, 2001b). The test as it was presented to the students is available in the appendices (Cardinot & Fairfield, 2020a). In this paper, we decided to focus on three topics of the Irish science curriculum: gravity (including planetary orbits), change of seasons and the Big Bang. These topics were selected after conversations with science teachers and a previous study conducted by the authors (Cardinot & Fairfield, 2019), in which a list of topics where students most often present alternative ideas was compiled. Furthermore, these topics have also been investigated in prior literature from other countries which provide a means of a cross-cultural comparison of our results.

The diagnostic test used to measure students' knowledge included both multiple-choice and open-ended questions to provide further clarification about the choice selection. A sub-group of 10 students also underwent a semi-structured interview to obtain verbal answers about the same questions from the written test. Due to time and logistical constraints (e.g., school availability), the interviews were conducted about one week after completing the knowledge test. Both the knowledge test and the interview were piloted before the present study was implemented. Participation in the interviews was voluntary, and approximately equal numbers of boys and girls were selected from each year. Each interview session took 25 minutes overall with three distinct sections, one for each major topic of the test, of approximately equal duration to investigate alternative conceptions separately. Interview protocol is given in the appendices (Cardinot & Fairfield, 2020b).

The knowledge test consisted of a series of questions to probe student thinking about astronomy, acting as a diagnostic tool to measure students' understanding. The questions often included common statements that contain alternative conceptions (distractors). These statements have different levels of scientific information included to investigate whether students would give a hybrid answer: a mix of alternative conceptions and scientific information. This type of answer could also provide further clarification of the reasons students might resist full acceptance of the scientific view.

Sample

The alternative conceptions elicited in this study were drawn from a knowledge test completed by 498 students between 12 to 15 years of age (54.7% Female, 44.9% Male, 1.1% Prefer not to say) split between first (37.4%, N = 186), second (32.7%, N = 163) and third (29.9%, N = 149) years of the Junior Cycle. Participants in this study were drawn from ten schools distributed across Ireland. Prior to the research, students, parents and teachers were requested to sign a consent form and, in this study, we only discuss data from those who permission was obtained. This interview included twelve randomly selected students in first year (N = 4), second year (N = 4) and third year (N = 4).

RESULTS

Findings were analysed to investigate if any significant association exists between gender, year group and the number of alternatives held. The chi-squared was performed at a p-value of .05, showing no difference in the proportion of alternative conceptions held by male and female students. ANOVA analysis was also performed to validate this finding further, indicating no statistical difference ($F(2,496) = .288, p = .75$) in the means of the number of alternative conceptions of males and females.

All student answers to open-ended questions were coded to classify the range of alternative ideas that they hold. Authors independently coded subsets of the data, and discussed any discrepancies. The code iteration cycle went through several discussions to refine the codebook each time until a final agreement on the application of the codes was achieved to establish inter-rater reliability of the final list of codes, and ensure the trustworthiness of the study. The final version of the codes had 80% agreement with a Cohen's kappa of .87. The lead author completed the entirety of the coding of the open-ended answers, discussing with the team each time any difficulties that arose during the coding process. Here we present the results obtained.

Students' Alternative Ideas

Gravity

The knowledge test contained nine questions to investigate alternative conceptions of gravity. The test focused on students' understanding of gravity on Earth and in space, what affects it, free-fall motion, and planet orbits around the Sun. In total, five dominant alternative conceptions emerged from students' written explanations on gravity-related questions. Interviews were also conducted to clarify student responses, allowing a more in-depth comprehension of the alternative conceptions shown by the students.

Alternative idea 1: No gravity in outer space or on the moon

The most common alternative conception showed by the students was related to the presence of gravity on the Moon. Students at all levels (see Table 2) strongly believe

Table 2. Students answer to question 4: "*Astronauts appear to be "floating" inside the space shuttle and on the Moon because...*" divided by 1st Year, 2nd Year and 3rd Year (N = 452)

	Year groups		
Question alternatives	1stY ear	2ndY ear	3rdY ear
There is no gravity in space	76.7%	80.7%	90.0%
They are falling in the same way as the Space Shuttle	2.6%	3.6%	0.0%
They are above Earth's atmosphere	9.1%	8.4%	0.0%
There is less gravity inside of the Space Shuttle	10.3%	6.0%	10%
No answer	1.1%	1.2%	0.0%

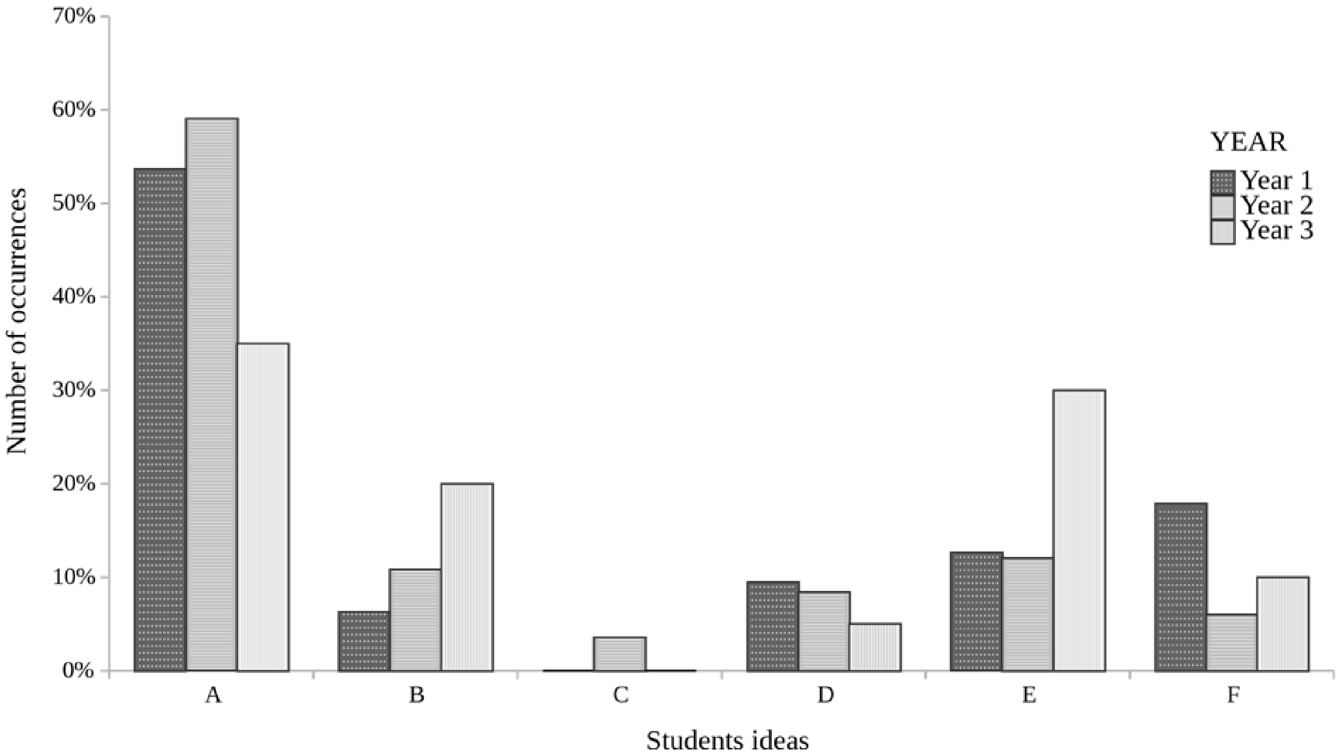

Figure 2. Themes from "explain your selection" on gravity in space multiple-choice question (Q3) (N = 408). Labels of the alternative ideas were grouped and coded as (A) There is no gravity in space and/or on the Moon; (B) The astronaut is falling towards/orbiting Earth; (C) Microgravity environment; (D) Gravitational force doesn't go beyond Earth's atmosphere; (E) I don't know; and (F) No answer

that there is no gravity on the Moon. When asked for clarification about this answer, students repeatedly used words such as "float", "do not fall" or "no gravity" to explain why, in their understanding, the Moon appears to not experience gravity, or cite the fact that astronauts are weightless in space. Figure 2 shows a summary and comparison of these alternative statements for each group.

Interestingly, 1st Year students often justify the belief of absence of gravity on the Moon by claiming that since there is no gravity in space and the Moon is in space, therefore, there is no gravity on the Moon. The statement "there is no gravity in space" (54%) is very persistent across all years. Although many students from the 2nd and 3rd Year groups (30.1% and 35.7%, respectively) recognise that outer space has gravity with varying strengths, the explanations used by students were highly varied ranging from ideas consistent with the scientific view to alternative ideas consistent with daily experiences. For example, the 2nd Year group suggested a variety of reasons for this including "almost everything in the universe no matter how big or small has to some extent gravity", "where there is something even a tiny atom there is gravity", "earth is a planet, so other planets might have gravity too", "wherever there is an atmosphere, there is gravity", "no gravity is in space and gravity has only been recorded on Earth". 42.3% of the 3rd Year group were able to articulate better the existence of gravity in space, mentioning that gravity is a force whose magnitude depends on objects' masses and distance (see Figure 2); however, 35% still indicated that there is no gravity outside Earth.

Alternative idea 2: Gravity as a magnetic force

Questions 5 and 6 ask what the nature of gravity is. The results, as shown in Table 3, indicate that the correct scientific idea that gravity is a force of attraction is persistent across all groups. However, very few students used concepts such as distance, direction, mass, and force to define gravity to support their choices. In fact, various students expressed the ideas that gravity is a

Table 3. Themes from question 5: "What is gravity?" open-ended question (N = 478). Students' answers to the question were group according to their year and, then, coded to summarise the ideas listed by them. Codes were generated using an inductive coding. Note that students used various claims to support their answer, therefore multiple codes could be assigned to a quotation during the coding processes

	Year groups		
Codes	1st Year	2nd Year	3rd Year
A force that pushes you down	96.7%	90.7%	95.6%
Magnetic force	75.4%	56.8%	43.1%
Force that depends on distance from planets	29.1%	38.4%	79.6%
A force defined by air/oxygen	25.3%	17.8%	15.0%
There is no gravity in space	78.1%	80.5%	56.3%
A force defined by Earth's core	1.2%	1.7%	1.0%

Table 4. Distribution of answers to question 7: *"What is the meaning of weight?"* multiple choice question (*N* = 498). Question adapted from Bar et al. (2016)

	Year groups		
Question alternatives	1st Year	2nd Year	3rd Year
Object is big or small	0%	0%	0%
Object is heavy or light	68.3%	48.6%	53.0%
Force of gravity exerted on the body	8.7%	28.7%	39.9%
Quantity of matter the body contains	13.3%	17.5%	3.0%
Force exerted on the support	9.7%	5.2%	4.1%

magnetic force since it attracts things to Earth (60.1%, *n* = 299). The comments below illustrate how students reinforced the idea:

Student A1: "Gravity is a magnetic force that brings objects to the surface of the planet or the centre of the Earth, caused by the core of the planet Earth or different planets" (Male, Year 3)

Student A2: "Gravity is a magnetic force that pulls us to the ground." (Female, Year 1)

Alternative idea 3: During free fall, the acceleration depends on objects mass;

Questions 7 and 8 investigated students' knowledge of the concepts of weight and freefall motion on Earth and the Moon. The first question explores alternative ideas about falling objects. The vast majority of students believe that a more massive object would fall quicker than lighter objects due to gravity. Our findings were consistent, in that 76.7% (*N* = 498) of the students believe that all other things being equal, greater acceleration is attributed to objects with greater mass. Furthermore, this increasing object's acceleration is a result of the increasing force of gravity as the object gets closer to the ground. Similarly, when asking students about falling objects on the Moon as 59.9% believed that, regardless of their "heaviness", objects would float away since, in their understanding, there is no gravity on the Moon. Over two thirds of the 1st year group (70.5%) responses followed this reasoning. In addition, although some students in 2nd Year (16.7%) identified that things would fall slower on the Moon, 69.9% hold the same alternative understanding as 1st Years that things drift away on the Moon due to lack of gravity.

In the same way, question 8 aimed to bring to the surface students' ideas about how gravity acts in space. Despite formal instruction about the concept of weight and gravitational force, students struggle with the idea that there is gravity in space as astronauts appear weightless in space. As shown in Table 4, very few students learn that weight is the force of gravity on an object by 3rd Year. 82.5% of students at all groups strongly believe that astronauts "float" in the space shuttle as it orbits Earth because there is no gravity in space.

Alternative idea 4: Gravity only relates to Earth

Question 9 aimed to determine students' ideas about the presence of gravity at various locations, such as on the Moon, on Earth, outside Earth's surface and on other planets. Table 5 shows the places where students believe that gravity exists. When a location is further away from Earth, students believe it is less likely to have gravity. Further information about student choices was gathered from the written responses to the question.

Combing the data from written responses reveals a significant difference in how students justify where objects are acted on by gravity, as shown in Figure 3.

Alternative idea 5: Planet Orbits

In question 12, students were asked to choose the image that best represents how planets orbit the Sun, then explain why the diagram was the best choice in their understanding. At all years, the majority of students believe that planets move on an elongated ellipse path around the Sun at the same speed (see Table 6). In addition, they could not articulate their understanding of orbital motion or had a limited notion of how planets orbit the Sun. For example, the 1st Year group described a "magnetic force" that keeps planets on the same path as they travel around the Sun, and was

Table 5. Distribution of answers to question 9: *"Where do you find gravity?"* multiple choice question (*N* = 498). Question adapted from Keeley and Sneider (2012)

	Year groups		
Question alternatives	1st Year	2nd Year	3rd Year
Earth's atmosphere	41.0%	40.6%	35%
Just outside of Earth's atmosphere	30.8%	36.2%	25.0%
the Moon	48.7%	29.0%	55.0%
Mars	43.6%	26.1%	40.0%
Jupiter	43.6%	24.6%	35%
Pluto	28.2%	20.3%	35%
Sun	17.9%	20.3%	25%
Distant stars	28.2%	18.8%	25%
Galaxies	28.2%	15.9%	35%
Far out in the distant universe	0%	0%	0%

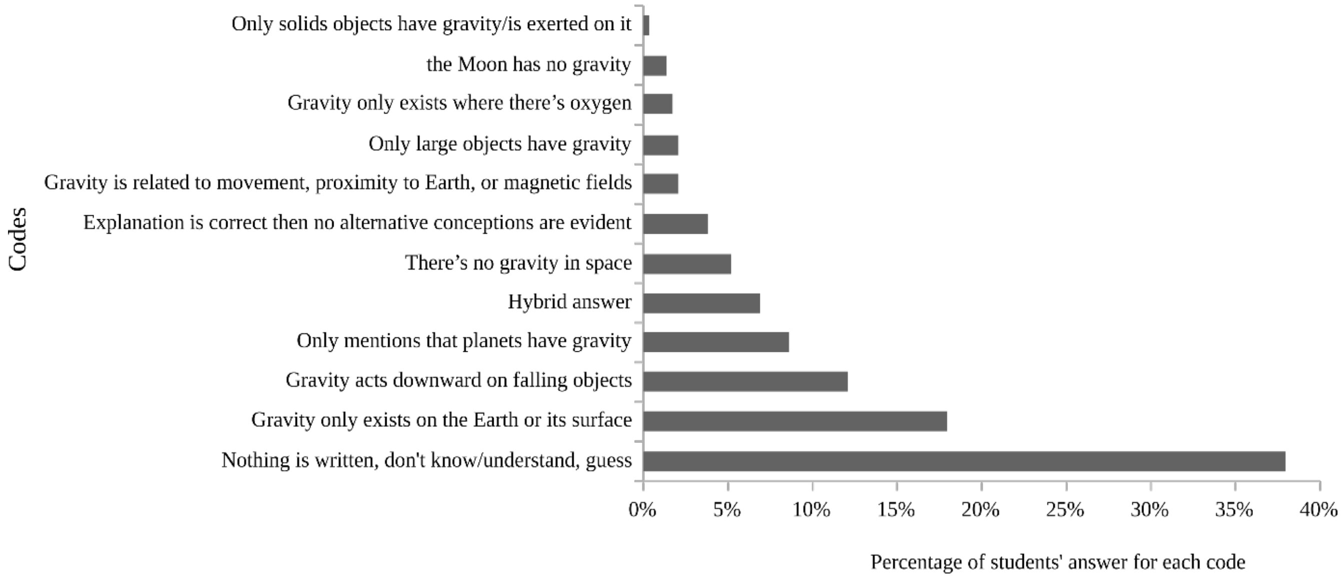

Figure 3. Themes from "explain your selection" on gravity in space multiple-choice question (Q9) (*N* = 498). Labels of the alternative ideas were grouped and coded per theme

Table 6. Student answers (*N* = 498) to planetary orbit question (Q12). Question adapted from Keeley and Sneider (2012) which presents six different solar system models: (A) elliptical path at different levels in relation to the Sun with planets at different positions; (B) circular orbit with planets at different positions but at the same level in relation to the Sun (flat Solar System); (C) planets follow the same orbit aligned in a elongated ellipse (all planets has the same distance to Sun); (D) elongated elliptical path at the same levels in relation to the Sun with planets travelling aligned in their orbits; (E) circular orbit with planets at the same positions and level in relation to the Sun (flat Solar System); and (F) model in which planets randomly orbit the Sun without a specific orbital path

	Year groups		
Question alternatives	1st Year	2nd Year	3rd Year
A	22.5%	18.8%	5.0%
B	4.8%	0%	30.0%
C	16.0%	11.6%	10.0%
D	54.9%	69.6%	55.0%
E	0%	0%	0%
F	0%	0%	15.0%
Missing	1.7%	7.1%	0%

unable to explain what causes this force. Also, most 2nd Year students' ideas (72.4%) used gravitational force to explain why objects do not escape their orbits, but suggested objects do not crash into the object they are orbiting because they have the right amount of gravity or some other alternative idea (see Figure 4). By 3rd year, students are expected to have a full understanding of the concept of gravity; however, in our findings, the group presented the same level as 2nd years. Students also frequently mixed the terms rotation and revolution, even in 3rd Year when they are expected to understand these concepts fully. As a result, students are unsure about the duration of each motion, though the 2nd year group

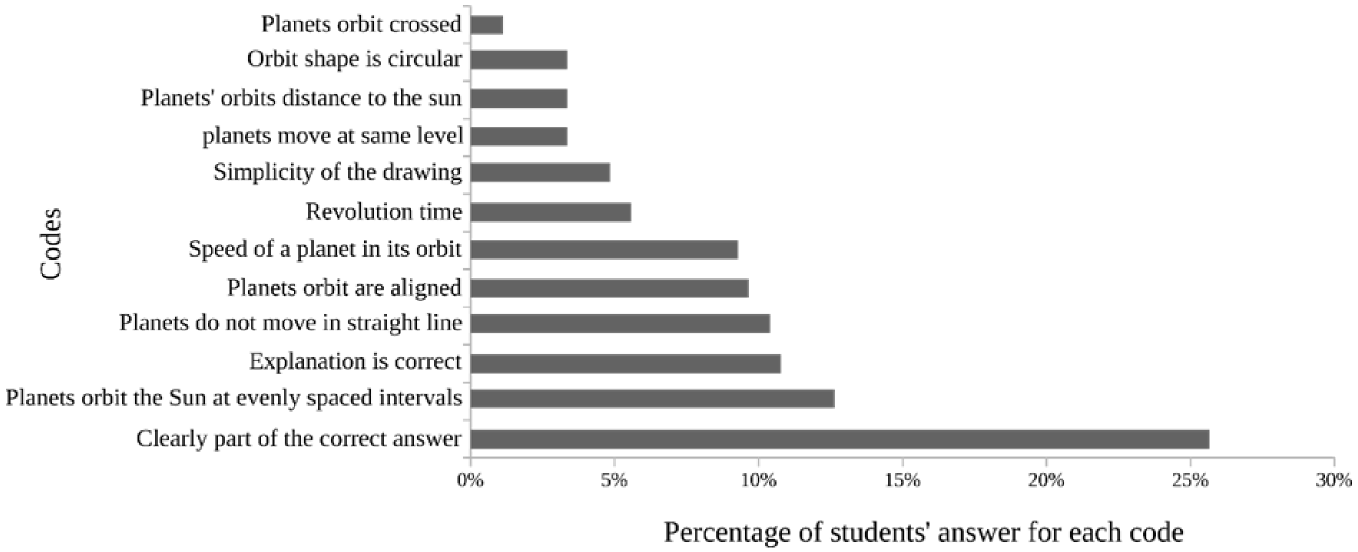

Figure 4. Themes from "explain your selection" on planetary motion multiple-choice question (Q11) (*N* = 269). Labels of the alternative ideas were grouped and coded per theme

Table 7. Student answers (*N* = 498) to question 10, in which three models of planets with a satellite are presented: each planet has the same mass, but the mass and distance of the satellites differ. Planets A and B have a natural satellite (i.e. moon) with the same mass, but Planet B's moon is two times further away from the planet. And Planet C has an artificial satellite with two times the mass of Planet A's, but has same the distance from the planet. This question aimed to elicit students' knowledge about gravitational interaction between a planet and its orbiting satellites (natural or artificial). Question taken from K. Williamson and Willoughby (2013); K. E. Williamson et al. (2013)

	Year groups		
Question alternatives	1st Year	2nd Year	3rd Year
Planet A	25.6%	24.6%	40.0%
Planet B	20.5%	24.6%	20.0%
Planet C	12.8%	14.5%	5.0%
Both Planets A and B	28.2%	24.6%	10.0%
All the same	10.3%	10.1%	15.0%
Missing	2.6%	1.4%	10.0%

presented higher understanding about the differences between rotation and revolution.

Alternative idea 6: The strength of gravity depends on the object distance to Earth or its mass;

Question 10 focused on how distance and mass relate to gravitational pull. In this question, students must combine their reasoning about mass coherently with the idea of distance. As shown in Table 7, there is a mixed understanding of this question showing that the distractor choices in the questions probed students' alternative conception about gravity, by providing situations where either mass or distance is different and asking how gravitational pull is affected.

To probe a more in-depth understanding of gravity, in question 11, students were asked: "Pretend that a tunnel was dug all of the way through the Earth. Imagine that a person standing at the surface holds a rock and drops it. Which answer best represents the path taken by the rock?" (Sneider & Ohadi, 1998). Common answers to this question are given in Table 8). The predominant answer (54.1%) was that the stone would pass directly through the tunnel. During the interview, a small group of students (12.7%) replied that a force would pull the stone towards the centre of the planet and then "melt" because of the high temperature in the Earth's core. Across all groups, there was a similar partially correct answer (37.5%) for the question stating that "the stone would go faster as it goes deeper but close to the centre the stone would slow down and it continues to move towards the other end of the tunnel, and repeat this process infinitely" (2nd Year, female). However, there was no mention of gravity in their statements or other concepts such as acceleration, showing that students at all levels had a fragmented understanding of the concepts involved in the question.

Seasons

The knowledge test contained seven questions to investigate students' understanding of what causes the seasons. The seasons are mainly a result of two things: the Earth's tilt, which causes the different hemispheres to have opposite seasons, and the revolution of the Earth around the Sun, so that as it travels different hemispheres receive different amounts of sunlight and heat. This topic is also included in the Irish primary curriculum, however it is only at Junior Cycle

Table 8. Students answer to question 11 about gravitational interaction on Earth (*N* = 498). Question taken from Sneider and Ohadi (1998)

	Year groups		
Question alternatives	1st Year	2nd Year	3rd Year
Rock falls toward Earth center	32.2%	17.6%	16.0%
Rock falls on the Earth's surface	1.0%	0%	0%
Rock passes through the tunnel to outer space	55.0%	57.0%	49.7%
Rock falls oscillating up and down and stop at the Earth's center	11.8%	25.4%	34.3%

Table 9. Students answer (*N* = 498) to question 13 about seasons and length of daylight, in which five students presented different ideas to explain the amount of sunlight in each season. Question was taken from Keeley and Sneider (2012) with these options: (A) my mom says it's because of daylight saving time; (B) my sister said Earth's tilt causes the Sun to be farther away in winter; (C) my father thinks the angle of sunlight must be the cause; (D) my brother says the Sun moves across the sky faster in winter; and (E) my neighbour thinks the Sun's path in the sky gets shorter in winter

	Year groups		
Questions alternatives	1st Year	2nd Year	3rd Year
A	5.1%	5.8%	5.0%
B	61.5%	50.7%	68.0%
C	2.6%	17.4%	1.0%
D	15.4%	5.8%	0%
E	12.8%	13.0%	15.0%
Blank	2.6%	7.2%	10.0%

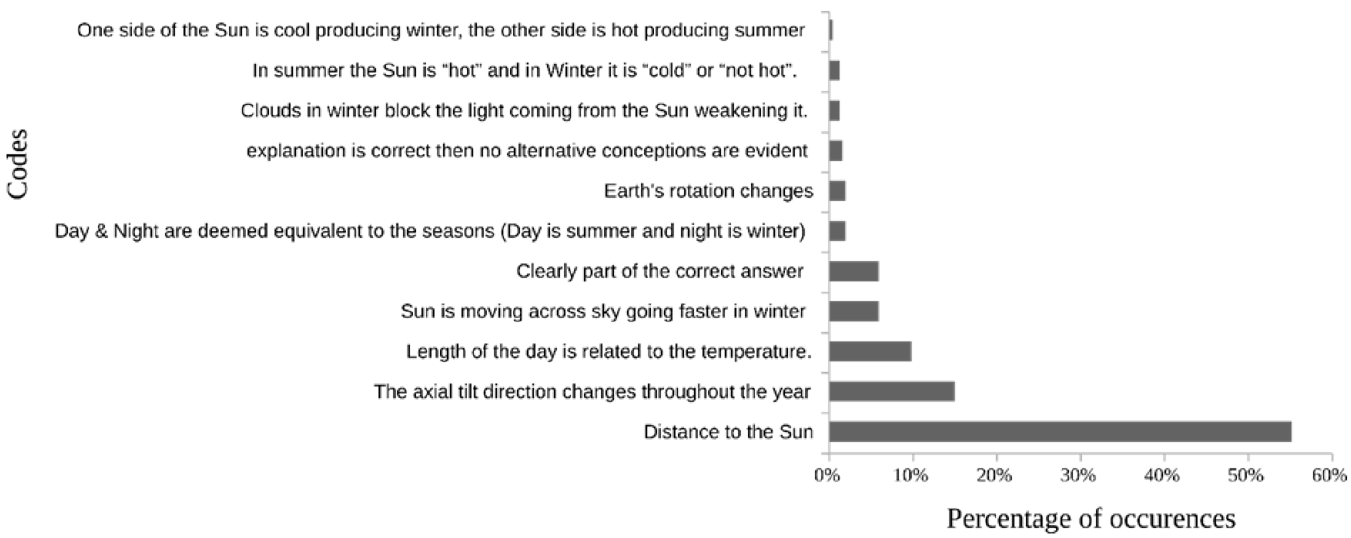

Figure 5. Themes from "explain your selection" to elicit students' ideas about the changing length of daylight with the change in seasons (Q13) (*N* = 254). Labels of the alternative ideas were grouped and coded per theme

(secondary) level that concepts are explored in further detail. For this reason, all years were expected to present different levels of information to explain the reason for the seasons.

Alternative idea 7: Seasons as a result of the Earth's distance to the Sun

Questions 13, 14 and 15 aim to investigate students' ideas of factors that affect the seasons. Interestingly, in question 13, only 9.6% of the students chose the correct option for the length of daylight changes during winter (see Table 9). 41.2% chose a partially correctly option with two concepts that students strongly believe to be related to the change in seasons: the Earth's tilt and distance to the Sun. This was confirmed in the "explain your choice" question where students gave answers like: "*it's best idea because the Earth is always moving and tilt causes it to be away from the sun for longer*" (1st Year, Female). Figure 5 shows a full list of students' reasons behind their choices.

In question 14 (*N* = 498), students were presented a diagram of the Earth's orbit around the Sun and asked to label the seasons for each hemisphere during a full year. Only 37.5% of the students correctly labelled the diagram, however, the incorrect answers revealed two interesting patterns. Firstly, 59.1% answered that the northern and southern hemispheres always experience opposite seasons throughout the year. Secondly, 36.4% correctly labelled seasons in the northern hemisphere but did not include the seasons for the southern hemisphere.

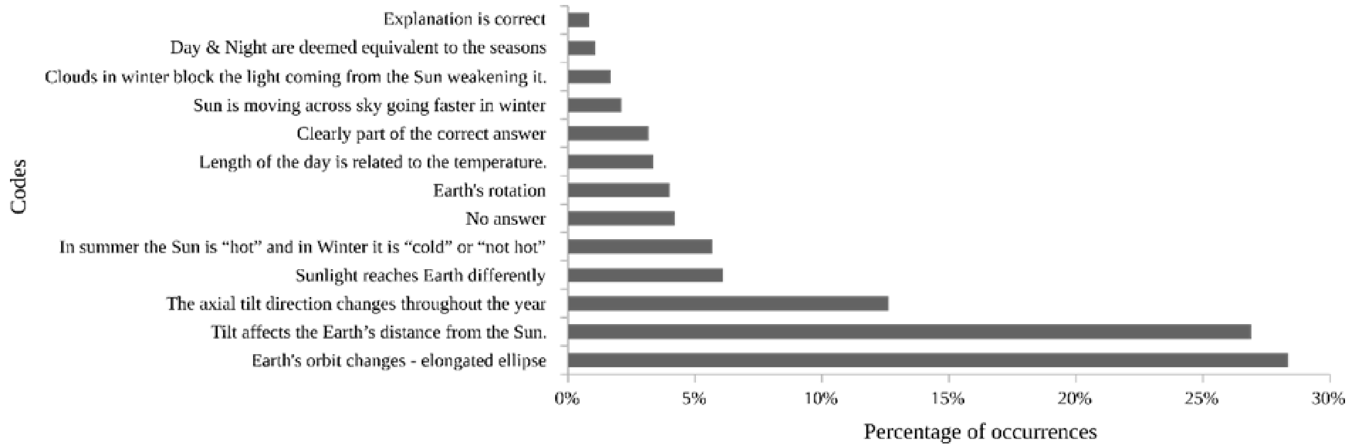

Figure 6. Themes from question 15 to elicit students' ideas about how the Earth's tilt relates to the seasons (N = 476). Students' answer alternative ideas were grouped and coded per theme

These results were further investigated in response to question 15 (*Explain how the tilts relate to the change in seasons*) in which a range of responses (N = 476) was elicited. The results obtained from the coding of open-ended answers to verify student reasoning are shown in Figure 6. Student ideas about the effects of the Earth's tilt on the change of seasons were highly varied. 28.4% of the students mentioned that the main reason for the change of seasons is the distance between the Earth and Sun throughout the year. This was followed by the notions that the Earth's tilt relates to change of seasons because it makes Earth closer to or further from the Sun (27.0%), Earth's tilt angle changes throughout the year (12.6%) and length of the day causes the seasons (4%). Another interesting aspect of this graph is that 6.0% of the students believed that the Sun only reaches certain parts of the Earth, causing it to shine on only half of the planet, making one part "hot" and the other "cold". During the interview, class discussions included:

Student A3: "As the Earth orbits the sun it will tilt more at same parts of the year so it would be sunnier in summer." (Female, Year 1)

Student A4: "I think when the northern hemisphere is tilted closer to the sun, it is warmer there so; therefore, it is summer there, and because the southern hemisphere is tilted further away from the sun, it is colder and therefore winter there." (Female, Year 2)

Student A5: "Earth's tilt relates to the change in seasons because as the Earth rotates it spins causing half of Earth to be warm and half of it to be cold." (Male, Year 1)

Alternative idea 8: Earth's tilt changes direction throughout the year

The alternative conception that Earth's distance from the Sun causes the seasons was mainly presented in two ways. Firstly, students expressed the belief that the Earth follows an elongated path around the Sun as shown in Figure 6, which follows a daily experience of the students that the closer they are to a source of heat, the hotter it feels. Secondly, there was a representation attributing the Earth's tilt direction as the cause of the seasons for the change in distance to the Sun. This representation could be described as a fragmented conception, in which students were aware that the Earth's tilt is somehow linked to the seasons, but used this information to justify the Earth as being "closer" or "further" from the Sun. This fragmented response is represented in student discourse:

Student A6: "when the direction of the axis changes, the place that has more sunlight in summer and the place with least sunlight has winter" (Male, Year 1)

Note that from their explanation, students acknowledge that the Earth's orbit is not an elongated ellipse. However, they assume that the direction which the Earth's axis is pointing changes so that the Sun shines more at different parts of the Earth to cause the seasons.

Alternative idea 9: The rotation of the Earth affects the seasons

20% of the students explained the seasons as a result of the rotation of Earth, without mentioning Earth's spin itself, i.e., there is summer on the side of the Earth that faces the Sun, and there is winter on the side that does not. This idea assumes that Earth does not rotate on its axis, but it completes one revolution around the Sun during the year. As some students further explained:

Student A7: "the Earth tilt means different bits of Earth is facing the Sun that's what changes the seasons" (Female, Year 2)

Student A8: "Earth's tilt relates to the change in seasons because as the Earth rotates it spins causing half of Earth to be warm and half of it to be cold" (Male, Year 2)

Student A9: "As it spins around each country gets a bit of sun for a few months and then when the world spins again, the countries that got sun before will now get no sun, and it's cold" (Male, Year 2)

The Big Bang

The Big Bang is a topic of high interest for the students. However, it is also the area that they most struggle to understand: approximately 25% of students

Table 10. Students choice per year (*N* = 498) for question 20 which asks about the expansion of the universe taken from Keeley and Sneider (2012). Question options are: (A) Matter is expanding into a huge empty void, (B) Space is expanding or stretching, so the distance between galaxies is growing, and (C) Space and matter are expanding, so galaxies are getting bigger and moving apart

	Year groups		
Question options	1st Year	2nd Year	3rd Year
A	13.7%	16.9%	27.1%
B	42.7%	40.9%	39.0%
C	43.6%	42.2%	33.9%

could not provide any answer to questions related to this topic, and only 5.5% could provide a correct explanation. The remaining answers were analysed to identify the most common alternative ideas present in students' reasoning. Our analyses revealed five different alternative conceptions, which students at all levels demonstrated in their statements, extracted from seven questions concerned with different aspects of the Big Bang.

Alternative idea 10: The Big Bang was an explosion

A recurrent conception in all groups was a sense that the Big Bang refers to an explosion or burst of some kind, similar to a bomb or a volcanic eruption. Table 10 summarises the results for question 20, which asks about the expansion of the universe (taken from (Keeley & Sneider, 2012)). Although 42.9% of students answer it correctly, most of those surveyed refer to the theory as an explosion in the explain your choice question. Students seem to mainly believe that the Big Bang is an explosion because of the name, because in popular media the word "bang" is often used to describe an explosion. In addition, many students assumed that a massive event was needed to generate the universe, as illustrated in the comments below:

Student A10: "billions of years ago a huge star exploded which sent matter flying and when there were enough bits together they formed planets and different energy formed the sun and other suns." (Female, Year 2)

Student A3: "the big bang theory was an explosion that essentially made the universe and the earth is still growing, making and growing." (Female, Year 1)

Student A11: "the big bang was an explosion that created energy and matter that eventually clumped together and made our planets, the matter and energy are still clumping together making more galaxies" (Male, Year 3)

Alternative idea 11: The universe had/has a centre

Interestingly, 16% of students believe that the universe has a common centre. This view could be related to the idea that the Big Bang was an explosion from some special point in the universe. Strong evidence of this alternative idea was also found during interview discussions as students reported that the "space exploded" from one point and then "everything was created". This alternative idea was mainly presented in the 1st Year group (~ 60%), but the 2nd (25%) and 3rd (~ 15%) Year groups also showed an understanding consistent with the conception that the universe has a centre. During the interview, students were encouraged to think-out-loud about the idea of the big bang:

Researcher: "Can anyone describe how the universe began?"

Student A7: "I think it started as something like small..."

Student A8: "no, it was a singularity everything was held in one place at the same, and it was very very hot and very very dense, and then it all started to be created."

Student A9: "The main elements for planets and galaxies had been compacted into a tiny particle and suddenly exploded, and it was cloud and dust for the first while of the birth of the universe".

Alternative idea 12: Some configuration of matter existed before the big bang

Another alternative conception that emerged was the idea that the entire universe started as a very tiny configuration of matter, smaller than a proton, from which everything was created. Approximately one-quarter of the students (26%) assumed that matter existed before the Big Bang and then "exploded" into other massive objects such as debris, gas planets, asteroids or stars. This response demonstrated a fragmented understanding of the theory: although they recognised that the space-time was generated after the Big Bang, they suggested that, for example, a very small and point-like massive object existed prior to the Big Bang across all year groups (1st (49%), 2nd (34%) and 3rd (17%)). Moreover, 10% of students said that matter was also distributed across the universe to create planets and stars at the time of the Big bang.

Alternative idea 13: There is no evidence for the Big Bang

Some students argued that there is no scientific evidence for the Big Bang. Students often described the theory as "just an idea", saying there is no scientific proof that it took place. This alternative conception was only found in the 1st year group (12%), but this group had also never had any formal instruction on the topic before. However, the students did understand that the Big Bang is a "theory", a concept they had learned prior to this study, but had a limited understanding of the term to recognise that scientific theories can have evidence supporting their validity. Students argued that:

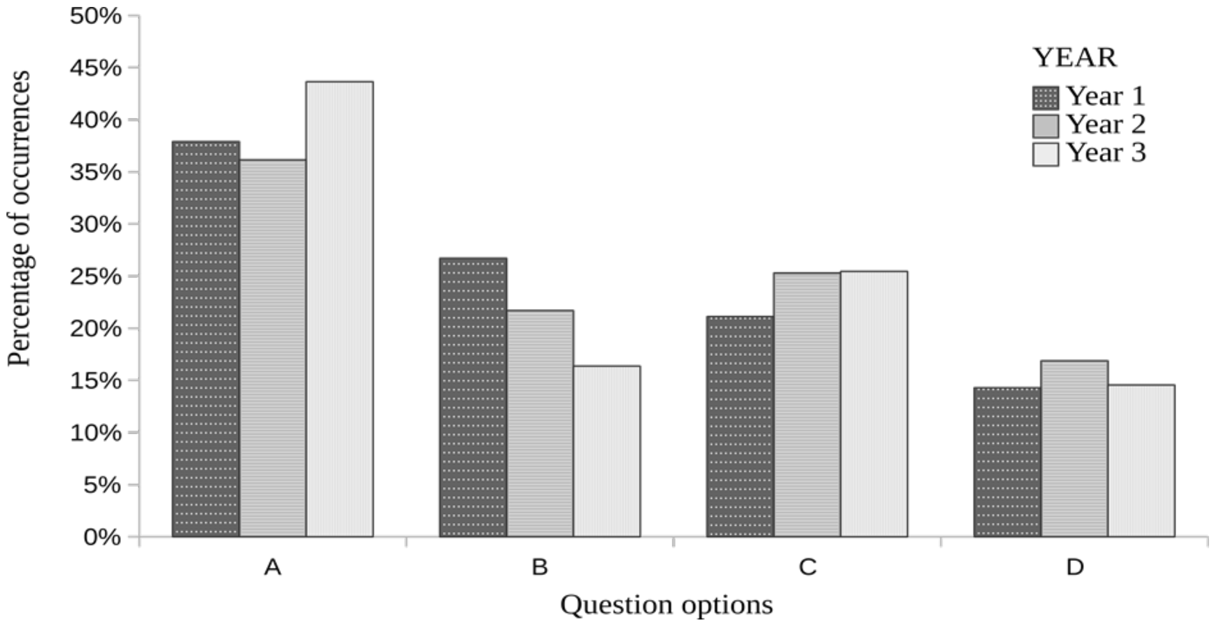

Figure 7. Students' choice by year (N = 460) for question 21 which asks about the description of the Big Bang taken from the Test of Astronomy Standards (TOAST) (S. J. Slater, 2009). Question alternatives are: (A) The event that formed all matter and space from an infinitely small dot of energy, (B) The event that formed all matter and scattered it into space, (C) The event that scattered all matter and energy throughout space, and (D) The event that organised the current arrangement of planetary systems

Student A4: "I think there is no physical evidence that the big bang theory happened, unlike the dinosaurs who had fossils and things like that." (Female, Year 1)

Student A12: "It is not scientifically proven because we cannot make measurements since we were not there at the time." (Female, Year 3)

Alternative idea 14: Evolution of the universe over time

35% of the students associated the Big Bang Theory with the formation or creation of something. Furthermore, students included very little, if any, detail in this question about the evolution of the universe. From student answer coding, 24% (N = 52) believe that the Solar System, Galaxies, and all other celestial bodies were formed during or just after the Big Bang. Figure 7 shows the students' choice for question 21 dealing with the explanation of the Big Bang.

Alternative idea 15: Expansion of the universe

When asked to define the Big Bang Theory, about 41.2% of the students, mainly in the 2nd (N = 99) and 3rd (N = 106) Year group, stated that the universe is expanding, but only 6% of those correctly described the meaning of expansion. Interestingly, students refer to the Big Bang as an expansion of matter into empty space, i.e., increase in the size of galaxies or planets. For example, student A12 (female, Year 3) mentioned that *"the big bang theory was a split moment in time when everything was one single part (singularity) and then bang... and there were planets and galaxies. I think galaxies are expanding and moving apart because they are collecting other objects that are floating around the universe"*.

Unpacking Students' Conceptual Resources

Here we describe the resources for understanding gravity, seasons, and the Big Bang theory that were most common across all year groups. In order to specify the conceptual resources in use, a systematic analysis of the literature was conducted on the use of resources framework in science education. The inductive approach was used to analyse the responses and identify the conceptual resources present in the students' reasoning. Figure 8 shows an example of the coding analysis conducted. The complete coding process employed is available in the appendices. These resources represent student thinking about the underlying concepts needed to explain these astronomical phenomena. Our goal is to explore how the students use the same resource in different contexts which may be correct and aligned with the scientific understanding in one instance but incorrectly activated in other problems.

Closer means stronger

The intuitive idea of closer means stronger (diSessa, 1988, 1993; Hammer, 1996) is an abstract cognitive frame that students use to make sense of the world around them (see more in Section *Theoretical Framework*). Although the idea is not incorrect, it can be misapplied depending on the context in which it is activated. This resource describes something that students experience in their day-to-day lives, such as the increase in temperature as one gets closer to a fire. In our results, students incorrectly activated this idea when trying to explain the change of seasons. Approximately 60% of the

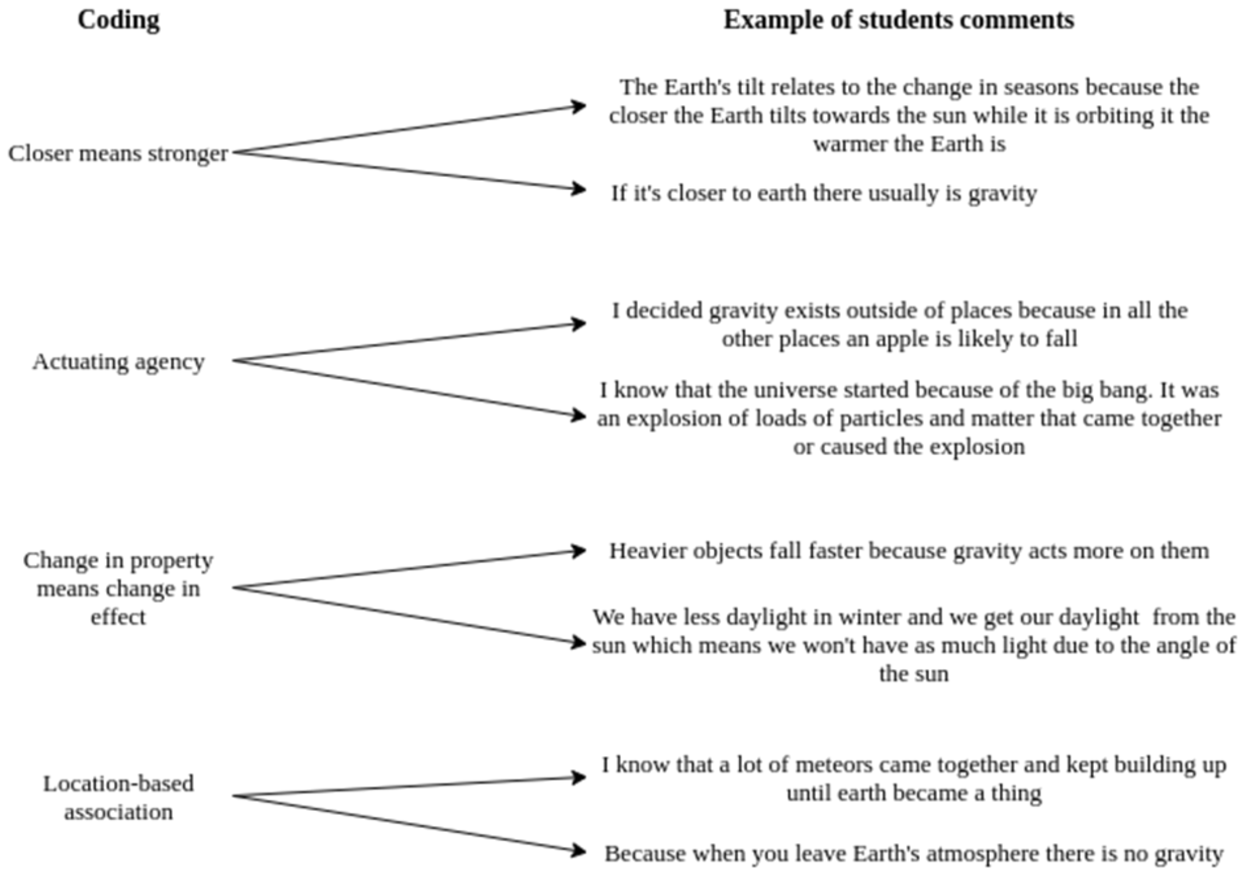

Figure 8. Examples of students' statements categorised within each code

students activated this resource when trying to explain the difference in temperature for each season, arguing that the Earth's proximity to the Sun causes the increase in temperature, and therefore hotter seasons (see Figure 4). Interestingly, the concepts used by the students when using this resources were highly varied, including the Earth's tilt to justify a change in distance, the rotation of the Earth to explain the amount sunlight received, an elongated ellipse model for Earth's revolution in combination with, for example, heavy clouds blocking heat or length of days affect the seasons.

Another way in which students activated this idea was when they were explaining the concept of gravity. From students' written and verbal responses (see Section *Gravity*), around ~ 35% associated the strength of the force of gravity with the distance between two masses, for example, when explaining that the gravitational force increase the closer to our planet. Although there were other resources involved in their reasoning about gravity, which will be discussed in the following sections, the resource "closer means stronger" in this case was correctly applied, aligning with formal physics by connecting the force of gravity and the distance between two masses. However, students also used this to justify gravity as only relating to Earth, with the consequence of no gravity in space (far away from Earth).

Actuating agency

This resource was first introduced by diSessa (1993) (p-prism force as a mover) and named as *actuating agency* by Hammer (1996); it refers to an agent, such as force, that causes some effect, such as motion. In our results, this resource came up into two different situations when students described gravity and the Big Bang. As shown in Section *Gravity*, students activated this resource to explain or predict whether a location has gravity, such as on Earth and the Moon. Although students correctly assume that gravity is the agent (i.e., force) responsible for falling objects, in their understanding an object falling to the ground is how we measure gravity. For example, when asked about the presence of gravity on the Moon, students often expressed the idea that objects would not fall there because of the lack of gravity; however, on Earth, there is gravity to pull objects towards the ground. Note that students' understanding is not entirely incorrect: gravity is an attractive force between two objects and does exert a downward pull (weight) on dropped objects that is proportional to the object mass. What is lacking is the comprehension of how gravity is measured and what affects it (mass and distance). When explaining falling objects on Earth, this resource is continuous with formal physics as gravity is the downward force that pulls objects towards the ground during a free fall. However, there is a limited and sometimes incorrect application of the resource when students argue that falling objects are a measure of the existence of gravity. About ~ 60% of the students incorrectly used falling objects as a way to determine if a location has gravity, i.e., if there is no gravity to pull things towards the ground, then objects float around. Interestingly, when asked to explain how they decided gravity exists in different locations such as planets, moons, and in outer space, across all years, a common statement was that "*if you drop an item, and it falls, then there is gravity*".

Another example of resource activation is when students describe the Big Bang. This topic has very little connection with everyday life, and a wide range of alternative ideas was elicited from students' responses (see more in Section *The Big Bang*). Among them is the idea that something was needed to initiate the evolution of the universe. In this case, the actuating agency resource was activated when students describe that the universe came from something, such as an explosion, or colliding stars and meteors. The activation of this resource suggests why an overwhelming number of students (~ 90%) believed that the Big Bang refers to an explosion, or the event that organised some form of pre-existing matter into the universe that we have today. Their ideas most often include atoms, a massive object such as a star or planet, or gas particles existing within empty space that collided to cause the evolution of the universe.

Change in property means change in effect

This resource is related to how the properties of an object enhance an effect, such as more mass means faster fall. From student responses, this resource was identified in two different situations. The first occurrence was observed when students explained how two objects of different masses fall at different rates. It is connected to their everyday experience that if we drop a heavy and light object together, the heavy one will get to the ground first. Although students had different levels of understanding about this topic as only 3rd Years had studied free fall and more advanced gravity topics, the idea that heavier implies faster was persistent among student at all levels regardless of their prior instruction. This resource is also connected with the common idea that the speed of an object during fall depends only on the mass, i.e., an object's acceleration increases in free-fall motion due to an increasing force of gravity as it gets closer to the ground. Indeed, the force of gravity does increase as the distance between two objects decreases. Though students' reasoning is canonically incorrect, their ideas are continuous with formal physics when they identify that gravity affects free-fall motion. In this case, the resource is incorrectly activated to justify a behaviour that students experience with formal physics.

In addition, the resource was also used by the students to explain seasons. About ~ 10% of their responses implied that the change of seasons is related to the amount of sunlight that reaches different parts of Earth throughout the year, and changes in the length of the day. Furthermore, students stated that more intense sunlight results in higher temperatures and longer daylight hours, allowing Earth to reach warm temperatures. It should be noted that, as shown in Section *Seasons*, students struggle to understand how the Earth's tilt is connected with the intensity of sunlight reaching Earth during the year. However, in this context, the resource was correctly activated and aligned with formal physics which associates the intensity of sunlight with seasonal changes and length of the days.

Location-based association

Finally, students use an Earth-based perspective resource to recall past events (e.g., time elapsed, distance) or to make a connection between the environment that they experience and formal physics (e.g., using Earth as a frame of reference). In our results, it was observed that students employed this resource to explain two concepts: the Big Bang and gravity. The Big Bang results showed several alternative ideas that students held across all years. Interestingly, students frequently unify the formation of the Solar System and the universe in their responses by mentioning that planets' formation took place just after or during the Big Bang. This perspective is reinforced with students' difficulty to grasp large-scale transformations over time, since many students assumed that the Big Bang refers to changes of objects within the universe, such as stars or asteroids colliding to create other celestial bodies. This shows the assumption that, similar to how life evolved on Earth, something cannot be created from nothing. About 30% of students assumed that something similar to a past event on Earth, e.g., a massive impact such as the asteroid that struck the Earth and killed off the dinosaurs, could also be the cause for the formation of the universe. In addition, the "bang" in the name reinforces this idea of a massive explosion or collision from one centre point outward into space, similar to a bomb, blast, or eruption.

Similarly, gravity is another example in which the students employed the location-based resource. Responses coded in this resource had to associate an Earth-based perspective for describing gravity explicitly. Some of the answers include the idea that gravity keeps things down on Earth (prevents things from floating away) or that it is linked with air or magnetism. Moreover, as shown in Section *Gravity*, students responses often had the understanding that gravity is concerned with or extends only as far as the Earth's atmosphere. For example, approximately 25% implied that in space (refer to the international space station, anywhere outside Earth or on the Moon) things would float because the objects are out of reach of Earth's force of gravity, hence the effect of weightlessness in space. Additionally, many students assumed that the presence or absence of air affects gravity, i.e., there would be no gravity on the Moon because there is no air (or atmosphere) on the Moon.

DISCUSSION

The variety of ideas inconsistent with formal physics identified in this work shows the importance of investigating students' preconceived ideas across all years to support better learning of astronomy concepts. The results were further analysed for a deeper understanding of the students' reasoning processes using conceptual resource theory. We administered a conceptual knowledge test, adapted from previously validated tests, and conducted interviews to clarify student reasoning about gravity, seasons and the Big Bang. These results could aid the tackling of alternative conceptions by showing educators the specific piece of information (diSessa, 1988; Hammer, 2000) or perspective missing for students to have a complete scientific understanding.

The importance of the ideas that students bring to the classroom to support the learning of new concepts has been widely explored among Physics Education Research groups (Brock et al., 2018; Kavanagh & Sneider, 2007; Larkin, 2012; Liu, 2005; Trumper, 2001a). Hailikari, Katajavuori, and Lindblom-Ylanne (2008) mention that new learning is related to students' prior knowledge as they often interpret new information based on what they already know (Disessa, 2014). As students progress through their education, they find it more challenging to overcome common sense beliefs originating from daily experiences as the alternative ideas can be very deep-rooted in student thinking (Hailikari et al., 2008). Our findings showed that even 3*rd* Year students held several alternative ideas about gravity, seasons, and the Big Bang. These results are consistent with the study conducted by E. Slater et al. (2018) and Trumper (2001b) with high-school students, showing that even after instruction, alternative ideas are not necessarily replaced by formal physics. It should also be noted that these alternative ideas about astronomy are not exclusive to the Irish population, as other researchers' international studies presented similar results with varying percentages (Aretz et al., 2016; Galano et al., 2018; Kavanagh & Sneider, 2007; Turk & Kalkan, 2018). Our results thus contain cross-sectional components that apply to other populations of secondary students.

Very little research exists about the use of resource theory in the context of astronomy education research. Hence, this study brings a new contribution to the literature by analysing student reasoning about astronomy using a resources framework (Hammer, 1996) which allows the identification of single ideas (or pieces of knowledge) that underlie students' reasoning and may be resistant to instruction (Hammer, 2000). These resources can also be indicative of why some alternative ideas are readily accepted by students regardless of their level of instruction (T. I. Smith & Wittmann, 2008; Wittmann et al., 2019). Moreover, our analysis revealed how these resources could be highly context-sensitive in students' thinking (Goodhew, Robertson, Heron, & Scherr, 2019), correctly activated in one setting and wrongly applied in other settings (Gupta, Hammer, & Redish, 2010), which prevents learners from understanding a concept fully. Section *Unpacking students' conceptual resources* shows the four different resources identified in our results and how each can be applied to different situations correctly or incorrectly. For example, the conceptual resource *closer means stronger* has been widely accepted as the resource of why students believe in the distance-model to explain the change of seasons (Brock et al., 2018; diSessa, 1993; Hammer, 2000; Sadler, 1998). Nevertheless, our analysis showed how the same resource is also activated when students discuss gravity (e.g., the closer to the Earth's core, the stronger the gravitational force). Although much of the recent research around students' ideas has focused on instructional approaches to reduce or eliminate the status of the alternative conceptions (Mills et al., 2016), the pattern of conceptual resource activation in student reasoning for different concepts provides information of where conceptual change approaches should focus instead of targeting the alternative ideas broadly.

Our findings concerning the concept of gravity showed that this is a very familiar word to students at all groups. However, all groups have alternative conceptions that do not match the level of comprehension that each year is expected to present. Section *Gravity* shows that students at all levels had a fragmented understanding of the concepts involved in the questions. These results are consistent with other studies (Bar et al., 2016; Kavanagh & Sneider, 2007; Palmer, 2001; Plummer et al., 2020; Ruggiero et al., 1985) in which secondary students also showed alternative conceptions of weightlessness, factors that affect gravity and the role it plays in free-fall motion. The alternative ideas found in this study are also connected with a lack of understanding of other fundamental topics such as speed, acceleration, force, magnetism and mass.

Moreover, students' reasoning about gravity involved mixed-resources that are both consistent with the scientific view, e.g., the closer to Earth's centre, the stronger the gravitational force (closer means stronger resource); and non-scientific such as when they mention that gravity could be only related to Earth (location-based resource). Furthermore, our results provide further support for the hypothesis that although there is a reduction in the number of alternative ideas as students advance in their grade levels, some of these conceptions remains regardless of instruction (Hughes, Lyddy, & Lambe, 2013; Potvin & Cyr, 2017; Sneider & Ohadi, 1998). However, there were similarities among the cohorts across most of the alternative ideas identified. As an example, the idea that there is no gravity on the Moon or that "things float away" in space is very persistent in all groups.

Regarding the change of seasons, students in all years strongly believe that it is a result of the Earth's distance to the Sun. A fragmented knowledge (diSessa, 1988) of the causes of the seasons was also demonstrated when students acknowledge the tilt of the Earth's axis as one of the factors that influence the seasons, but incorrectly imply the tilt changes the distance between the Earth and Sun, and when students associate the amount of sunlight in each season with only that part of the planet being illuminated by the Sun (i.e., confusion with day and night cycle). Furthermore, only 9.6% of the respondents were able to correctly explain the reason for the seasons, although 37.5% identified the opposite seasons for each hemisphere. Surprisingly, these alternative ideas were also found in the 3rd year group, when students are expected to fully understand the mechanisms behind the change of seasons. The *closer means stronger* resource (Hammer, 2000) was the most used by the students to describe the change of seasons as it is quickly developed from their daily experience with sources of heat. Also, when asked about the planet's orbit around the Sun, the student mostly believed in the elongated ellipse, which contributes to the incorrect distance-model for the change of seasons. These results further support previous studies (Blown & Bryce, 2010; Brunsell & Marcks, 2005; Driver, Rushworth, Squires, & Wood-Robinson, 2005; Trumper, 2001a, 2001b) showing that distance-theory is the most common idea used by the students at all levels to explain the seasons. Furthermore, among the correct answers, the students mostly activated the *more influence means more effect* resource to explain how the amount of sunlight changes during a year. However, they also showed a limited understanding of the role of the Earth's tilt on the seasonal changes.

Overall, students have a range of alternative ideas about the Big Bang. Students were more curious about this topic but also held the highest number of alternative ideas (six in total). Aligned with previous studies (Aretz et al., 2016; Bailey et al., 2012; Prather et al., 2002; Trouille et al., 2013), one of the main ideas held by students is that the Big Bang was an explosion that created the universe. Also, the explosion model was associated with the idea that the universe has some centre, and some matter must have existed before the Big Bang. Interestingly, several students correctly refer to the Big Bang as an expansion of space but struggle to explain the meaning of the term "expansion" correctly.

Additionally, very few students provided information about the evidence for the Big Bang and often assumed that the universe has always existed, which could be connected to a lack of understanding of how scientific research is conducted or how astronomers answer questions related to the origin of the universe. It should be noted that the level of instruction for this topic varies across groups and only the 3rd Year group was expected to hold a more scientific understanding of the topic since it is the last year of the Junior Cycle level. The resources used by the students, *actuating agency* and *location-based association*, reveal that a context-dependence perception constrains the students' alternative ideas about the Big Bang as they often use Earth as a frame of reference. In particular, the idea that some matter existed in a point-like shape until it burst is associated with their experience when observing explosions on Earth (i.e., something is needed to trigger the explosion). Our findings also indicate an inaccurate spatio-temporal understanding given that almost one-quarter of the students assumed that planets and all other celestial bodies in the universe were formed during or just after the Big Bang. Thus, these results suggest that it is paramount to introduce learners to spatio-temporal thinking skills to support the conceptual understanding of the evolution of the universe and the place of Earth in space and time.

Although students hold many alternative ideas about each topic, we believe that these can be used as seeds for further instruction rather than issues to correct. However, preconceived ideas can also represent a barrier for learning when they limit a student's ability to interpret a new situation (Council, 1997). The conceptual resources identified in the reasoning process provide details about the way students' thinking is continuous with formal physics and the variety of ideas that educators could encounter when teaching secondary students. Indeed, ideas that are inconsistent with the scientific view present a challenge for new learning and require a radical reorganisation or replacement (Limon, 2001) of prior knowledge, i.e., a conceptual knowledge change process (Vosniadou, 2012). For example, instructors could intentionally start developing a spatio-temporal thinking skill (Rajpaul et al., 2018) prior to introducing concepts like the Big Bang and seasons, to help students reorganise their information about the evolution of the universe as well as correctly visualise planets' orbits around the Sun.

Moreover, the alternative ideas presented here showed evidence of hybrid understanding (L. B. Smith & Samuelson, 2013) in which students combine concepts that are aligned with formal physics and knowledge obtained from daily experiences. The presence of this hybrid understanding, even in the 3rd Year group, demonstrates the difficulty in overcoming the alternative ideas through traditional instruction (Kober, 2015). From students' reasoning, formal concepts are often adapted to fit preconceptions, e.g., mentioning that expansion refers to an explosion of space or that the Earth's tilt changes the distance to the Sun to justify a highly elliptical orbit. This offers evidence for the need to uncover students' alternative ideas prior to instruction in conceptually challenging topics (Tobias, 1994) in order to prompt students to review and build upon their prior knowledge new models consistent with the scientific view. However, the process of conceptual change is not an easy task and requires a long time (Ozdemir & Clark, 2007) as regardless of prior¨ instruction, senior students are still likely to hold the same alternative ideas as first years. Therefore, there is a need for more research on ways to expose students' alternative conceptions about astronomy and instructional approaches that fully engage and challenge these alternative ideas.

Limitations

There are two main limitations associated with this study that may present scope for further research. Firstly, the small number of students involved in the study may limit the extent of these conclusions about astronomy knowledge held by the Irish secondary students, as they may not be fully representative of the whole population. Thus, more research with a larger sample and in other contexts would increase external validity of our findings. Secondly, the scope of the study covered gravity, seasons, and the Big Bang, which do not represent all topics involved in the Earth & Space curriculum. Therefore, the results should be interpreted with caution as they only represent one aspect of the rich knowledge that students possess.

CONCLUSION

This study aimed to contribute to a better understanding of alternative ideas about gravity, seasons and the Big Bang held by Irish secondary students, in order to describe and analyse the conceptions that students develop along their learning trajectory. In total 15 alternative ideas were identified across all groups of students, namely:

1. There is no gravity in outer space or on the moon;
2. Gravity is a magnetic force;
3. During free fall, the acceleration depends on objects mass;
4. Gravity only relates to Earth;
5. Planet orbits are highly elliptical;
6. The strength of gravity depends on the object distance to Earth or its mass;
7. Seasons are a result of the Earth's distance to the Sun;
8. Earth's tilt changes direction throughout the year;
9. The rotation of the Earth affects the seasons;
10. The Big Bang was an explosion;
11. The universe had/has a centre;
12. Some configuration of matter existed before the Big Bang;
13. There is no evidence for the Big Bang;
14. The universe was created during or just after the Big Bang (rapid evolution of the universe);
15. The Big Bang is an expansion of matter into empty space, i.e., galaxies and planets' sizes are increasing over time.

Our identification of the four most common conceptual resources in student discourse when explaining each topic showed a hybrid understanding in which formal physics is blended with daily experiences. These resources and their activation elucidate why students easily accept some alternative ideas and how they adapt formal physics to fit their current model of a concept, e.g., if gravity only relates to Earth, there is therefore no gravity on the Moon. In addition, the results presented here call for more research into the ways these concepts are taught at secondary schools, given that many alternative conceptions were found equally among all year groups. Further research should look into methodologies that promote cognitive conflict to elicit students' prior beliefs and to design comprehensive instruction that can support students in constructing robust scientific knowledge about astronomy.

Author contributions: All authors have sufficiently contributed to the study, and agreed with the results and conclusions.

Funding: This research is supported by CAPES-Brazil Grant No. 88881.128466/201601.

Declaration of interest: No conflict of interest is declared by authors.

Acknowledgements: We wish to thank Dr Veronica McCauley, Dr Jessica Hoehn, Dr Claudia Fracchiolla, Dr Shane Bergin and Dr Marcos Cardinot for their helpful feedback throughout this project. Finally, we wish to thank all educators, students and parents for helping us to collect the data for making this study possible.

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