SN Soc Sci (2023) 3:15
https://doi.org/10.1007/s43545-022-00603-5

ORIGINAL PAPER

# An investigation on alternative ideas on thermal phenomena of pupils with and without learning difficulties

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Received: 29 July 2022 / Accepted: 23 December 2022 / Published online: 12 January 2023


**Abstract**
In the last decades, constructivism has dominated Early Childhood Science Education. Within this context, alternative ideas of pre-school pupils have been thoroughly explored and analyzed. Nevertheless, research on these ideas in individuals with learning difficulties remains scarce. Aiming to fill this gap, the present study explores alternative ideas on thermal phenomena of pupils with learning difficulties and compare them with those without learning difficulties. For this purpose, an experimental investigation was conducted with 25 pupils with learning difficulties ($M$ = 72,50 months, s.d. = 8,11) and 25 pupils *without learning difficulties* ($M$ = 72,50 months, s.d. = 9,50). Drawing from constructivist theory, a structured, computerized tool (A.I.H.E.T) was developed to fulfill research's goal. Findings suggest that pupils with and without learning difficulties use almost the same ideas on thermal phenomena, on a different frequency though. The results support further the findings of other research, according to which inclusive science education not only is feasible but also it has great benefits for students with and without learning difficulties.

**Keywords** Science education · Alternative ideas · Thermal phenomena · Learning difficulties

## Introduction

In the last decades, constructivism has dominated Early Childhood Science Education and determines to a great extent the teaching interventions and strategies that are implemented in everyday school practices (Ravanis 2017). Central role to this theory holds the notion of 'alternative ideas'; these are ideas that pupils have about a number of natural phenomena in advance of their schooling and are often different

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from scientifically accepted views. These ideas are derived from intuitions and that sort of reasoning stays with the pupils for many years until there will be an organized context to contradict with these intuitions (Kornelaki, 2023). Therefore, these ideas are likely to play a crucial role in the learning process as they often act as barriers in the conceptualization of the physics concepts. Along this line, the teacher should be aware of these alternative ideas and be ready to adjust their teaching in response to them (Driver et al. 1985). While these ideas have been extensively studied by a number of academics and researchers in typical education context, this has not been the case for pupils that lie on special needs spectrum (Ergazaki and Ampatzidis 2012; Delserieys et al. 2017; Fragkiadaki and Ravanis 2021). Indeed, there are some researchers who have tried to explore constructivism in the particularly demanding field of special education (Brigham et al. 2011; Duhaney and Duhaney 2000; Ruban 2005; Kaliampos et al. 2020; Scruggs and Mastropieri 1994; Villanueva and Hand 2011; Villanueva et al. 2012). The respective literature focuses on the barriers of implementing inclusive science education in terms of infrastructure and provisions (Chunawala 2014), teachers' training and readiness (Chunawala 2014; Reynaga-Peña et al. 2018), as well as the benefits of inclusive inquiry-based science education to all students (Abels 2014; Villanueva et al. 2012). There is some published research which points out students' initial conceptions in inclusive science education (Rott and Marohn 2018; Stinken-Rösner et al. 2020). In the former research, the initial conceptions are conceived as independent of students having learning difficulties or not, but they are considered essential for science teaching and learning as well as for students' engagement in science classes (Rott and Marohn 2018; Stinken-Rösner et al. 2020). Nevertheless, few previous research has explored and compared students' alternative ideas individually for students with and without learning difficulties (Baysen and Dagli, 2014; Kaliampos 2021). A new prominent trend within Early Childhood Science Education, the so-called Early Childhood Special Science Education, is formulated in its initial phase trying to encompass the trends that govern science education within special needs context (Kaliampos 2021). Moving toward this line, the present study aspires to investigate alternative ideas on thermal phenomena of pupils with learning difficulties (LD) and compare them with those without learning difficulties.

## Learning difficulties

Learning difficulties is a modern and quite topical issue in educational reality (Panteliadou and Botsa 2007). Students that fall into this category constitute a substantial proportion of the general school population (Chu and Lo 2016; Williams 1993). This target group faces general difficulties in school's demands (Leung et al. 2007) and comprise a heterogeneous group of children with impairments that vary from mild to severe. In particular, at the one end of the spectrum lie pupils with severe, profound, and multiple impairments in learning, while on the other end stand pupils with less severe impairments who are nevertheless capable of achieving academic standards through appropriate teaching interventions (Colley 2020).

The term 'learning difficulties' is the most widely used to identify the severe or specific difficulties that individuals experience in the process of acquiring academic knowledge and literacy skills. The research efforts of scholars have contributed to the creation of many definitions, which are subjected to constant critical analysis and adaptation (Ysseldyke, 2005). One major and representative definition is the following that considers learning difficulties as 'a dysfunction in one or more basic psychological processes involving the understanding or use of language, written or spoken, that may manifest itself in an imperfect ability to listen, think, speak, read, write, spell, or perform mathematical calculations' (Brigham et al. 2011, p. 224). These difficulties of pupils are likely to play a major role in learning acquisition. It is noteworthy that the term 'learning difficulties' moves in a different direction from that of specific clinical definitions used in the past that tended to target or stigmatize those children (Dare et al. 2017). Nevertheless, it is a matter of debate whether it actually achieves this goal, as each child with special needs is already stigmatized as soon as it is placed in the special needs' spectrum.

Learning difficulties therefore acts as a generic term with a variety of definitions that refer to children with normal intelligence that face up difficulties in one or more academic areas (Carroll et al. 2014). Specifically, it is a lifelong neurodevelopmental disorder that result in difficulties in the acquisition and use of academic skills (reading, speaking, writing, mathematics), regardless of the average or above average cognitive abilities (Lipka et al. 2019). Individuals with learning difficulties are mainly characterized with a significantly reduced ability to understand new or complex information, to learn new skills (impaired intelligence) and to deal effectively alone (impaired social functioning). Quite interestingly, some children exhibit specific learning difficulties in specific areas, such as literacy and mathematics. In general, learning difficulties are characterized by intellectual disabilities, attention, and memory issues as these pupils often struggle to retain different kinds of information (Lee et al. 2001).

One of the most important and fruitful movements which emerged within education field in the current century is that of inclusion (Timor and Burton 2006). The theory of inclusion is based on serious issues concerning human rights, equal opportunities, social justice, and efforts for less restriction environments for all pupils, as well as educational policies that promote a better future for them (Moran and Abbott 2002; Timor and Burton 2006). It's the keystone in a strong educational policy which promotes rights and high standards of all learners and narrow inequalities (Moran and Abbott 2002; Stinken-Rösner et al. 2020). The idea of inclusion is that all pupils, regardless of the abilities or disabilities, are accepted as they are, and are part of the school community and participate equally in the school practices (AuCoin and Berger 2021). So, in line with the idea of diversity that seem to gain ground in the recent years in the field of education (Sliwka 2010), individual differences must be thought as opportunities for improvement of learning and teaching practices and not as a problem (Moran and Abbott 2002).

Within the scope of inclusion, children with learning difficulties ought to participate in the general classroom that is modified and correspond to the needs of students (Ralli et al. 2011). Along this line, the specific characteristics and needs of these pupils should be recognized and taken into account in order to promote a successful and equal school environment (Colley 2020; Pui 2016). Further research and practices should encourage the perception of inclusion and specify the way that this would be implemented into teaching diverse subjects, physics among them, in mainstream classes.

## Thermal phenomena: the scientific point of view

According to the scientific point of view, temperature, along with volume and pressure, is a basic parameter which characterizes a system. The knowledge of this parameter gives us the capability to make predictions about the state of a system, when an external factor intervenes on it (Hewitt 2014). In contrast, heat describes the interaction between two systems. Specifically, it represents the energy which flows from a system with a higher temperature to a system with a lower temperature (Hubber and Jobling 2015). This energy stops flowing when the temperature of the two systems becomes the same (Hewitt 2014). So, for example, if we bring in contact a hot metal with a cold piece of wood, energy in the form of heat will start flowing from the metal to the piece of wood, until the temperatures of these two materials become equal. Regarding thermal expansion and contraction, they are characterized by a change in the volume of materials with the corresponding changes in temperature. This change is clearly visible in metals, which is considered to be the appropriate material to approach this phenomenon (Hewitt 2014).

## Pupils' alternative ideas on thermal phenomena: heat, expansion, and contraction

A great number of science educators have conducted research on pupils' understandings of thermal concepts. The results show that pupils often hold alternative ideas that differ from the scientifically accepted ideas of these phenomena. In what follows, pupils' alternative ideas on heat as well as thermal expansion and contraction are presented.

Regarding heat, pupils often treat it as a substance, which is usually invisible and exists within objects. Being capable of moving, heat acts as a fluid that can either move within an object or flow to another object (Kaliampos and Ravanis 2019). This mental representation seems to have its roots in caloric theory; a theory that existed in the eighteenth century and stated that the particles of a fluid, which is called heat, can be attracted by any object which is near them (Hewitt 2014). Within this theory, heat behaves as a substance which has all the ordinary characteristics of a material, such as mass and volume (Erickson 1979).

The fact that heat is conceptualized by pupils as a fluid material makes them believe that cold is a fluid material, too. Clough and Driver (1985) point out that these two materials are considered by the pupils to be opposites and that their only common characteristic is that they are both capable of moving. So, these two fluids can exist simultaneously in the same object. Being hard objects, pupils believe that metal objects attract, retain, and absorb the cold heat (Lewis and Linn 1994).

Quite interestingly, pupils often consider heat as a main characteristic of an item, a feature that belongs to the object (Erickson 1979). Tiberghien (1980) points out that these pupils do not recognize heat as an intermediate between two objects. Everything contains its own heat. So, for example, a metal is always cold or sand on a beach is always hot. Pupils, who hold this view, are likely to have a causal reasoning of the following type: 'because a metal is cold, it cools' or 'because the cotton is hot, it heats' (Tiberghien 1980, p.297). Consequently, hot objects cool naturally, and cold objects heat up, respectively. In addition, pupils often associate temperature with the size of an object (Driver et al. 1985).

Consequently, it seems that pupils' thinking consists of a local character, while their way of dealing with natural phenomena is dominated by experiences from everyday life as well as early pre-collective forms of thinking (Bar and Galili 1994). That is, the representations they have are linked to specific thoughts about the phenomena, materials and tools they use (Ravanis 2022).

The way pupils conceptualize thermal expansion and contraction has not been extensively studied in Early Childhood education framework. The limited findings show that, while pupils mainly refer to heating and cooling as the cause of the contraction and expansion of metals, they can hardly explain it on kinetic theory of molecules (Lee et al. 1993). As Ravanis et al. (2013) point out, pupils tend to perceive the changes of metal objects but find it difficult to attribute them to expansion or contraction. To quote a student of their research 'It will not pass… not now… It is changing and it can't happen…. It is changing… I don't know what else is happening…. 'When we heat it, it will find difficulty in…it won't be able to pass through the ring…'.

### Research questions

Drawing from Early Childhood Special Science Education, the current study aspires to expand constructivist theory in the particularly demanding field of special education. In particular, it tries to explore (alternative) ideas on thermal phenomena of Early Childhood education pupils with and without learning difficulties. To do so, it tries to answer the two following research questions:

(1) What are the alternative ideas on thermal phenomena of pupils with and without learning difficulties?
(2) How are these alternative ideas compared among the two study *groups?*

## Materials and methods

### Participants

To address the above-mentioned research questions, an experimental investigation was conducted with a total of 50 early childhood education participants, aged 4–7 years old, divided into two groups. Group 1 consisted of 25 pupils (mean age = 72,50 months, s.d. = 8,11), all having a formal diagnosis of learning difficulties from Centre for Differential Diagnosis and Support (Dimakos et al. 2016). Group 2 consisted of 25 pupils without learning difficulties (mean age = 72,50 months, s.d. = 9,50). All participants were recruited from kindergarten and primary schools located in two semi-rural areas of West Greece. It is important to underline here that in Greece, pre-school is two-year compulsory education and an integral part of formal education.

According to the teachers of the classes involved, students didn't have any prior learning experiences about the topic. That is, none of the pupils had come across in their school lessons to any kind of organized activity or reference concerning thermal phenomena. Prior to conducting the study, the researchers received approval from the teachers as well as the Research Ethics Board designated by the University of Patras and particularly from the Department of Educational Science and Early Childhood Education. In addition, parental permission and consent were obtained for all pupils who participated in the study. Moreover, parents were analytically informed by the researcher about the research context such as that: (a) the interview will last approximately 15–20 min and it will be recorded, (b) children's personal information would be fully protected, and (c) children could withdraw at any time from the research process.

## Research instrument

The research was conducted through individual semi-structured interviews (Bryman 2016), which lasted approximately 15–20 min. The interviews were conducted via a structured, digital tool which was developed to explore alternative ideas on thermal phenomena of pupils with learning difficulties (A.I.H.E.T.—Alternative Ideas Heat Exploration Tool) and meet the needs of remote research. A.I.H.E.T. is comprised of 5 tasks divided into two basic sections (see full tool in Appendix). The first section deals with thermal conduction in objects and consists of 3 tasks. Particularly, A1 depicts a copper tube whose one end is set on fire from a gas fire, A2 shows two metal tubes of different length whose ends are set on fire while A3 illustrates two spoons made of different material (metal and wooden), which are placed in different glasses full of hot water (A3). Pupils were *encouraged, during the interviews,* to develop their ideas about what they think will happen to the objects if they come into contact with heat. The second section deals with thermal expansion and contraction of metals and consists of 2 tasks. In these tasks pupils are asked to communicate their ideas about what would happen if a metal ball (B1) and a metal tube (B2) get heated for a long time.

All tasks of A.I.H.E.T. are based on previous research in the respective field in academic literature (Kaliampos and Ravanis 2019; Ravanis 2022). In the case of A.I.H.E.T., the tasks appear in digital form as new technologies attract pupils' interest and enhance their motivation to actively participate in the learning process (Stanberry and Raskind 2009).

There is consensus about the benefits of introducing ICT tools in education, not as sole means to approach a concept or phenomenon, but supplementary to multiple methods (Smetana and Bell 2012). Prerequisite for the latter though is the teacher's guidance and support to students while using the digital tools in order the students to benefit from their use (Smetana and Bell 2012). Therefore, ICTs can't replace teacher's role in learning process (Lorenzo and Trujillo 2018), but only offer multiple representations to students. In the case of the present research, the use of the A.I.H.E.T. tool allowed the implementation of the intervention amid the pandemic of Covid-19. In case the intervention hadn't be affected by the pandemic's restrictions, the tool would have been used supplementary to face-to-face intervention enriched with hands-on experiments.

In addition, all A.I.H.E.T. tasks illustrate familiar and representative images from everyday life, accompanied with movement and visual effects, as visual learning helps pupils to conceptualize the phenomenon they deal with, which in turn contributes to the validity of the measurement (Witzel et al. 2001).

A.I.H.E.T. tool was pilot tested with two pupils, the first aged 5 years old and the second with learning difficulties aged 6 years old. Results showed that no changes were needed in the layout and the structure of the tool. These two pupils were not included in the final sample.

### Research procedure

In this study, a qualitative design method was utilized, collecting qualitative data that support a more analytic and in-depth comprehension of pupils' representations (Bryman 2016). As mentioned above, pupils' descriptions were collected through remote individual semistructured interviews (Bryman 2016). Due to the pandemic of Covid-19, research was conducted entirely remotely through WebEx platform. Particularly, both researcher and participants, along with their parents, logged in from their houses and during the interview the researcher, using the A.I.H.E.T. digital environment, asked pupils questions about the thermal phenomena. The interviewer addressed questions to the pupils encouraging them to express their thoughts, treating them with sensitivity and without prejudice. Additionally, to confirm the validity of the responses, the researcher was paraphrasing some of the questions and, when the pupils' responses differed, the researcher was asking pupils for more explanations (Pogiatzi et al. 2022).

## Data analysis

Data analysis was based upon verbatim transcribed data of the discussions between the researcher and pupils along the A.I.H.E.T. tool utilization. Particularly, a content analysis method was conducted which is a high flexible method since it can be applied to a wide variety of different kinds of unstructured textual data (Bryman 2016, p. 304–305). Inter-coder reliability in the process of content analysis was ensured by designing a coding manual that provides complete lists of all codes and the corresponding categories as well as guidance on how to interpret these categories (Bryman 2016). Following the manual's directions, two independent researchers read through the transcribed data and evaluated whether pupils' answers fell within the scientific model, based on a three-point scale (sufficient, intermediate, and insufficient) (Kaliampos and Ravanis 2019; Ravanis 2005). In particular, in category a (sufficient responses), the answers in which pupils seemed to have grasped the scientifically acceptable ideas on thermal phenomena depicted in the tasks were classified. In category b (intermediate responses), the answers in which pupils' reasoning was characterized by a mixture of both scientifically acceptable and unacceptable ideas were classified. Finally, in category c (insufficient answers), the answers in which pupils either expressed ideas that did not entail any scientific argument or did not give an answer at all were classified. To test the inter-coder reliability, we calculated Cohen's kappa. This coefficient measures the level of agreement between two coders in terms of coding. According to this coefficient, values that exceed 0.7 are considered very satisfactory (Bryman 2016). The Cohen's kappa coefficients for each of the five tasks were (A1 = 0.87, A2 = 0.90, A3 = 0.86, B1 = 0.90, and B2 = 0.93) and therefore the inter-coder reliability is considered very satisfactory.

In addition, in the result section frequencies and percentages of each category are presented for the two groups of pupils in all tasks. Finally, with a nonparametric Mann–Whitney independent sample test, it was investigated whether there are significant differences in pupils' responses in the two groups. The Mann–Whitney test is used to compare differences between two independent groups since the dependent variable is ordinal (3 categories) (Field 2018).

## Results

### First section of the A.I.H.E.T

In what follows, the rates of pupils' responses for each task of the first section of A.I.H.E.T. are presented (see Table 1). Quite interestingly, in all three tasks, the Mann–Whitney test did not reveal statistically significant differences (A1: $U = 295.5$, $p = 0.7$, A2: $U = 255.5$, $p = 0.2$, A3: $U = 258.5$, $p = 0.3$).

### Task A1

Almost 12% of pupils with LD gave an appropriate response in regard to the scientifically accepted view on task A1. These pupils predicted that the copper tube will

**Table 1** Percentages of pupils' responses on the first section of A.I.H.E.T

| | Task A1 | | Task A2 | | Task A3 | |
|---|---|---|---|---|---|---|
| | LD | TD | LD | TD | LD | TD |
| Sufficient responses | 3(12%) | 5(20%) | 8(32%) | 11(44%) | 7(28%) | 7(28%) |
| Intermediate responses | 15(60%) | 13(52%) | 14(56%) | 13(52%) | 13(52%) | 7(28%) |
| Insufficient responses | 7(28%) | 7(28%) | 3(12%) | 1(4%) | 5(20%) | 11(44%) |

be heated along its entire length and justified their view by stating that the heat will occur gradually along the length of the tube. A typical example is the answer: 'The whole pipe will be heated all the way to the end; the fire is hot and it's slowly going further' (LD.17).

The majority (60%) of pupils with LD gave a response which was described as 'intermediate.' Here, pupils predicted that the copper pipe will be heated up along its entire length but did not give a scientific reason for this. To quote a pupil 'There will be a lot of fire and the pipe will get into trouble and it will go bad and burn all over' (LD.6).

Finally, a group of pupils (28%) with LD answered inappropriate in regard to a scientifically accepted idea. That is, pupils did not predict that the copper pipe would be heated up to the end. Typical answers are as follows: 'The pipe will only burn where the fire is' (LD.5) and 'It will break' (LD.20).

Almost 20% of pupils without LD responded adequately to this task. The majority of them (52%) gave an intermediate response such as 'It will burn the whole pipe' (Without LD.9). On the other hand, 28% of pupils gave inadequate answers as the following 'It will rust from the fire' (Without LD.19).

As it was stated above, 12% of pupils with LD gave a scientifically acceptable answer on task A1. However, of great interest are the alternative ideas that emerged *from* the remaining percentage of pupils' responses. Specifically, the first alternative idea is that pupils do not predict that the pipe will be heated all the way to the end. Instead, they state that the pipe will only be heated where the fire burns, as the heat is not capable of being transferred (Kaliampos and Ravanis 2019). This idea corresponds to 16% of the sample's responses and is evident in the following pupil's response: 'The pipe will only burn where the fire is. The fire cannot go further' (LD.5). As a second alternative idea, the local character of pupils' responses was detected, which constitutes early pre-collective form of thinking and derives from their everyday experience (Bar and Galili 1994). Here pupils responded at a rate of 8% that the pipe will be heated and melted. To quote two indicatively answers 'The tube will melt' (LD.3) and 'The tube will get hot and soften… it can melt it' (LD.11). Finally, the alternative idea that emerges (8%) is that pupils' representations are related to specific thoughts about the materials (pipe) and the phenomena used (heating with fire) (Ravanis et al. 2022). Indicative responses are the following: 'The pipe will rust' (LD.16) and 'The metal pipe will break' (LD.20). Table. 2.

### Task A2

32% of pupils with LD gave an appropriate response in regard to the scientifically accepted view on Task A2 stating that the smaller pipe would be heated up to its end more quickly than the larger pipe and justified their answer by mentioning the heat spread in metal pipes. To quote a pupil 'The small metal pipe because it is smaller and will burn more quickly, the big one is bigger and will burn more slowly' (LD.14).

The majority (56%) of pupils with LD managed to predict that the small tube would get heated more quickly, without giving a scientific reason for their answer though. Typical examples are the following 'The small one because it is small

**Table 2** Percentages of alternative ideas expressed by pupils on task A1 of A.I.H.E.T

| Pupils' alternative ideas | Percentage % LD | Percentage % Without LD |
|---|---|---|
| Scientific sufficient response | 12 | 20 |
| Heat is not transferred along the entire length of the object | 16 | 12 |
| Local character of pupils' responses derived from their everyday experience | 12 | 24 |
| Pupils' representations are related to specific thoughts about the materials and phenomena used | 8 | 12 |
| Other responses | 52 | 32 |

and the big one is slow' (LD.4) and 'The small one because it is small and will get hotter faster while the big one will burn up to the middle' (LD.15).

Finally, 12% of pupils with LD answered inappropriate in regard to a scientifically accepted idea giving responses such as 'None, because the fire will not get there' (LD.3).

On the other hand, 44% of pupils without LD managed to give a scientifically accepted response. The majority of pupils (52%) gave the correct answer without mentioning heat though. Indicative is the following answer 'The little one because it is smaller' (Without LD.17). 4% of pupils here gave inappropriate answers such as 'The big pipe will burn faster' (Without LD.24).

Taken from above, 32% of pupils with LD gave a scientifically acceptable answer on task A2. However, of particular interest are the alternative ideas of pupils that emerged on the task. Specifically, the first alternative idea detected at a rate of 12% was that pupils perceive that in the tube with large size the heat will go faster (Paik, Cho and Go, 2007). They typically responded, 'The big pipe will heat up faster because it is bigger and therefore the fire will go faster' (LD.10) and 'The big pipe will burn faster… since it is big the fire goes faster… in the small one it goes slower because it is small' (LD.21). The second alternative idea that emerges is that pupils do not anticipate that the pipes will be heated up all the way (Kaliampos and Ravanis 2019). This idea corresponds to 8% of the sample responses and is evident in following pupil's answer: 'No pipe will be heated to the end, because the fire will not reach there' (LD.3). Table. 3

**Table 3** Percentages of alternative ideas expressed by pupils on task A2 of A.I.H.E.T

| Pupils' alternative ideas | Percentage % LD | Percentage% Without LD |
|---|---|---|
| Scientific sufficient response | 32 | 44 |
| In the pipes with large size the heat will go faster | 12 | 4 |
| Pipes will not be heated up all the way | 8 | 4 |
| Other responses | 48 | 48 |

### Task A3

28% of pupils with LD predicted that the metal spoon would be heated up more quickly, attributing this to the distinct materials the two spoons are made of. To quote a pupil ‘The metal spoon will heat up faster because it is metal, the wooden spoon will not heat up’ (LD.24).

Almost half of pupils with LD (52%) gave an answer which was classified as ’intermediate’. Here, pupils predicted that the metal spoon would get hot more quickly, without referring to the nature of materials though. Indicatives are the following answers ‘The metal spoon will get hot and if you touch it you will burn’ (LD.4) and ‘The metal one because it is harder’(LD.3).

A fairly large group of pupils (20%) with LD answered inappropriate in regard to a scientifically accepted idea. Here, pupils mainly predicted that the wooden spoon would get heated up more quickly. To quote one pupil ‘The wooden one because it heats up faster, the metal one is cold’ (LD.14).

*Pupils without LD* responded adequately to this task at a rate of 28%. A similar percentage (28%) gave an intermediate answer such as ‘The metal spoon will heat up faster’ (Without LD.4). A fairly high percentage of pupils (44%) gave inadequate answers and were classified in the corresponding category.

As it was stated above, 28% of pupils with LD gave a scientifically acceptable answer on task A3. However, of great interest are the alternative ideas that emerged on the remaining percentage of pupils’ responses. Specifically, the first alternative idea is that pupils predict that the wooden spoon will be heated up faster and even catch fire (Kaliampos and Ravanis 2019). This idea corresponds to 16% of the sample responses and is evident in the following response ‘The wooden spoon because it is made of wood and when it is left in the heat for a long time it will catch fire and burn’ (LD.15). The second alternative idea relates to the local character of pupils’ responses, which constitutes early pre-collective form of thinking and derives from their everyday experience (Bar and Galili 1994). Here pupils responded, at a rate of 12%, that the wooden spoon will break as soon as it is left in hot water for too long. To quote one of them ‘The wooden spoon is made of wood so it heats up faster… and if you leave it in for a long time it will be in pieces’ (LD.22). Finally, the alternative idea that emerges at a rate of 12% is that metal objects attract, retain, and absorb cold, while they are able to transfer it to other objects (Lewis and Linn 1994). Table. 4.

## Second section of the A.I.H.E.T

In what follows, the rates of pupils’ responses for each task of the second section of A.I.H.E.T. are presented (see Table 5). Quite interestingly, in all two tasks, the Mann–Whitney test did not reveal statistically significant differences (B1: $U = 302.5$, $p = 0.8$, B2: $U = 307$, $p = 0.9$).

**Table 4** Percentages of alternative ideas expressed by pupils on task A3 of A.I.H.E.T

| Pupils' alternative ideas | Percentage % LD | Percentage% Without LD |
|---|---|---|
| Scientific sufficient response | 28 | 28 |
| The wooden spoon will be heated up faster and catch fire | 16 | 38 |
| The wooden spoon will be heated up and break | 12 | 8 |
| The wooden spoon will be heated up, while the metal spoon will make the water cold | 12 | 8 |
| Other responses | 32 | 18 |

**Table 5** Percentages of pupils' responses on the second section of A.I.H.E.T

| | Task B1 | | Task B2 | |
|---|---|---|---|---|
| | LD (%) | TD (%) | LD (%) | TD (%) |
| Sufficient responses | 15 (60) | 17 (68) | 10 (40) | 12 (48) |
| Intermediate responses | 5 (20) | 1 (4) | 7 (28) | 2 (8) |
| Insufficient responses | 5 (20) | 7 (28) | 8 (32) | 11 (44) |

## Task B1

The majority of pupils with LD (60%) gave an appropriate response in regard to the scientifically accepted view on task B1. Specifically, pupils predicted that the metal ball will not pass through the ring after it is heated and attributed this to the expansion of metal objects due to temperature fluctuations. Typical of this category is the following response: 'The metal ball will not pass through the hoop… it will not pass because the ball is made of metal and the fire has made it bigger' (Without LD.12).

The percentage of pupils with LD who gave a response that was classified as 'intermediate' was 20%. Here, pupils predicted that the metal ball will not pass through the ring but did not attribute this to the expansion of metal objects. Illustrative is the following quotation: 'The metal ball won't go through, because there is something in it and it is stuck in the ring' (LD.9).

Finally, 20% of pupils with LD answered inappropriate in regard to a scientifically accepted idea predicting either that the metal ball would pass through the ring or that it would not pass, attributed it to various causes though. To quote a pupil 'The metal ball will pass through the ring as before… I don't know why it doesn't pass through in the end, it probably got stuck' (LD.15).

Pupils without LD responded adequately to this task at a rate of 68%. On the other hand, 4% of pupils gave an intermediate answer, stating that: 'No, the metal ball will not pass through the ring… it will not pass because it is hot and stuck somehow' (Without LD.19). Almost 28% of pupils gave inadequate responses and were *coded in* the corresponding category.

As it was stated above, 60% of pupils with LD gave a scientifically acceptable answer on task B1. However, of great interest are the alternative ideas that emerged on the remaining percentage of pupils' responses. Specifically, the first alternative idea is that pupils assume that the metal ball does not pass through the ring because it is hot and the heat sticks to the ring. This idea corresponds to 20% of the sample responses with typical answers being ‘The ball will not pass… it will stick to the hoop… and that’s how the craftsman makes a fire and sticks the irons together… I’ve seen it’ (LD.1) and ‘The bullet stuck and that’s why it won’t go through… you put it in the fire and it got hot and when it touched the ring it stuck and couldn’t go through’ (LD.2). The second alternative idea relates to the local character of pupil’s responses, which constitutes early pre-collective form of thinking and derives from their everyday experience (Bar and Galili 1994). Here pupils indicated, at a rate of 12%, that the ring will get smaller because the hot bullet touched it. To quote one of them ‘The bullet won’t go through… yes, it won’t pass because the hot bullet touched the ring and it got smaller’ (LD.22). Finally, the third alternative idea that emerged (8%) is that the two metal balls depicted in the task were not the same. That is, pupils believe that the metal ball that went through the hoop had different size from the one that was heated. Indicative is the following answer: ‘This bullet won’t pass because it’s different… it’s bigger… that’s why it won’t fit… this time you put in another bullet, it’s not the same’ (LD.25). Table. 6

### Task B2

40% of pupils with LD gave an appropriate response in regard to the scientifically accepted view on Task B2 attributing tube elongation to the expansion of metals. To quote a pupil ‘The metal tube will become 7 cm, that is very correct, that is, it will grow a little, because it was in the fire and the fire made it bigger’ (LD.11).

28% of pupils gave intermediate responses; that is predicted the correct answer without referring to metal expansion at all. Typical was the following answer ‘It will get bigger; it will go 7’ (LD.4).

In addition, 32% of pupils with LD answered inappropriate in regard to a scientifically accepted idea. Illustrative answers of this category are the following ‘It will stay the same 6 cm’ (LD.2) and ‘It will be a little smaller, because it was heated too much and shrunk’ (LD.10).

Pupils without LD responded adequately to this task at a rate of 48%. In contrast, 8% of pupils gave an intermediate answer simply stated that ‘The metal pipe will go 7 cm…. I don’t know…’ (Without LD.6). Finally, 44% of pupils gave inadequate responses and were classified in the corresponding category.

**Table 6** Percentages of alternative ideas expressed by pupils on task B1 of A.I.H.E.T

| Pupils’ alternative ideas | Percentage % LD | Percentage % Without LD |
|---|---|---|
| Scientific sufficient response | 60 | 68 |
| Metal ball does not pass through the ring because it is hot and stuck | 20 | 20 |
| The ring shrinks as it comes into contact with the hot metal ball | 12 | 8 |
| The two metal balls depicted in the task are not the same | 8 | 4 |

Taken from above, almost half of pupils with LD (40%) gave a scientifically acceptable answer on task B2. However, of particular interest are the alternative ideas of these pupils that emerged on the task. Specifically, the first alternative idea, held by 20% of pupils, states that the metal pipe will remain the same, unaffected by the fire (Ravanis et al. 2013). To quote one pupil 'The pipe will stay the same, 6 cm… it will not be harmed by the fire… no matter how much you put a metal pipe in the fire it will not be harmed, the fire will not harm it' (LD.2). The second alternative idea is that pupils predict, at a rate of 28%, that the metal pipe will be shrunk by the fire (Ravanis et al. 2013). Indicative is the following response: 'The metal pipe will go 5 cm… when you heated it, it got smaller and smaller… the fire made it smaller…' (LD.1). Finally, the third alternative idea emerged at a rate of 8%, is that pupils believe that the pipe will be cut in two if it gets heated too long. Typical is the following response 'The fire will heat the pipe… it will bend and cut in half…' (LD.23) Table 7.

## Discussion

The present study tried to explore alternative ideas on thermal phenomena of pupils with and without learning difficulties and compare them. Our findings seem to be in line with those that have been found on the international literature for pupils without LD. Particularly, regarding propagation of heat to objects, the majority of pupils with LD recognize*s* that *heat* will spread along the entire length of the pipe and will not just be refined at the point where the fire comes out of the gas flame. Similar data are found in the literature, where pupils tend to associate heat with a moving substance (Erikson, 1979; Kaliampos and Ravanis 2019; Paik et al., 2007). Consequently, *in those pupils' mind*, heat is capable of moving along objects.

Quite interestingly, a percentage of pupils with LD do not anticipate that the tube will be heated up to its opposite end. As Kaliampos and Ravanis (2019) pointed out, children do not recognize that the tube will be heated up to the edge. It could be assumed that pupils' answers are based on thoughts, experiences, and data from their everyday life. This is consistent with Bar and Galili's (1994) research, who highlighted the local nature of pupils' responses, which constitutes early pre-collective

**Table 7** Percentages of alternative ideas expressed by pupils on task B2 of A.I.H.E.T

| Pupils' alternative ideas | Percentage % LD | Percentage % Without LD |
|---|---|---|
| Scientific sufficient response | 40 | 48 |
| The metal pipe will remain the same, it will not be affected by the fire | 20 | 4 |
| The metal pipe shrinks by the fire | 28 | 40 |
| The pipe will be cut in two parts | 8 | 0 |
| Other responses | 4 | 8 |

form of thinking and derives from their everyday experience. The same is argued in Duit and Treagust' research (1998) as cited in Lederman and Abell (2014).

In addition, the common alternative idea often stated by pupils according to which heat acts as a permanent property of the material (Clough and Driver 1985; Tiberghien 1980) was identified in the sample of the current study, too. In particular, pupils with LD pointed out that the metal spoon will not be heated up quickly as it is naturally cold, whereas the wooden spoon will be heated up because it is burned immediately. Similar data are presented by Lewis and Linn (1994), who found that young children perceive that metal objects attract, retain, and absorb cold.

Regarding the expansion and contraction of metal objects, a significant percentage of the sample satisfactorily predicted that the metal sphere will not pass through the metal tube after it's heated up, though without referring to any kind of expansion or contraction. Ravanis et al. (2013) came to the same conclusion, finding that pupils perceive the changes that occur in metal objects, but have difficulty attributing them to contraction and expansion. Similar conclusions were reached by Lee et al. (1993), who reported that children conceptualize heating and cooling as the cause of metal contraction and expansion but have difficulty explaining it in terms of molecular motion.

These findings suggest that pupils aged 4–7 years, whether they are classified as learning disabled or not, have similar alternative ideas, thoughts and difficulties about thermal phenomena. This assumption can act as the starting point and reinforce the academic belief of a holistic, inclusive education for all pupils, with a common curriculum, *acknowledging* specific talents or difficulties (Amor et al 2019; Sakiz 2018). That is, pupils of diverse origins, including pupils with LD, can be taught thermal phenomena along with their peers and be expected, with the appropriate scaffolding of their teachers, to successfully participate in science activities. This finding is in line with other researchers who have also promoted inclusive education for teaching and learning science to pupils with difficulties (Gebbels et al. 2010; Moin et al. 2009; Turner 2008; Villanueva and Hand 2011).

There is rigorous research from which we draw data about science and special education and the way these two fields meet and share common goals to achieve "science for all" (Taylor and Villanueva 2017; Villanueva et al. 2012). The former research focuses on barriers to the learning process and the ways with which the movement "science education for all" can be achieved. In regard to the barriers, the authors mention teachers' readiness, implying the need for pre- and in-service training, as well as practical obstacles teachers encounter in their everyday practices, such as lack of equipment and specialized assistance, students' difficulties in communication, and more. Another barrier mentioned is the way science is approached in classroom given the available resources. At the same time, the authors highlight the benefits science education has to students with a variety of disabilities in comparison with other disciplines, such as mathematics and linguistics. Finally, the authors stress the importance of synergies between science and special education in order to achieve greater science success (Taylor and Villanueva 2017; Villanueva et al. 2012). The present paper contributes to this extent focusing on students' alternative ideas on thermal phenomena in the frame of a micro level study. The results of this study can support teachers' design of interventions considering the similarities and differences among the students' conceptions with and without learning difficulties. Of course, further research is needed on the one hand to more students, while on the other to more concepts and phenomena from the field of science education. Finally, what would interest both science and special education fields is to study whether the identification and addressing of students' alternative ideas support greater science success to students with learning difficulties as it is concluded in published research for the students without learning difficulties (Boilevin et al. 2022).

## Study limitations

A limitation of the current study relates to the small sample of the research. What is more, the sample has been recruited from specific regions of Greece,; therefore, it is not a nationally representative sample. Further research extending to a multiple number of pupils from diverse regions could also add value to our findings. In addition, another limitation concerns the fact that due to Covid-19 restrictions, the study was conducted through WebEx, with pupils being at different places from the researcher. Possibly, a meeting of the researcher with the participants, in advance of the research procedure, could make pupils feel intimacy and express themselves freely. Finally, a limitation of the study is related with the diagnosis itself as it is a fact that diagnoses are not comparable, and it is sometimes unclear why a child has a diagnosis and another one has not.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s43545-022-00603-5.

**Acknowledgements** The authors would like to thank both the parents who permitted their children to participate in this research as well as the children themselves

**Author contribution** MAK held the research idea, posed the research questions, designed and implemented the research, and collected the data. KL and ACK analyzed the data. GK assisted in the research design, wrote the text, and organized the whole team. All the authors contributed in the discussion section.

**Funding** The research study was not funded by any organization.

**Data availability** The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Disclosure** The authors declare that they have no conflict of interest, No potential conflict of interest was reported by the authors.

**Ethical approval** (a) The research study was approved by the Research Ethics Board designated by the University of Patras and, particularly, by the Department of Educational Science and Early Childhood Education (protocol code 10/3–3-2020). (b) The authors confirm that all research studies were conducted in accordance with the Declaration of Helsinki regarding the relevant guidelines/regulations applicable when human participants are involved.

**Informed consent** Prior conducting the study, the researchers received approval from the teachers and parental permission while consent was obtained for all pupils who participated in the study.

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