Research

Experimental Scientific Values in Inclusive Education as a Challenge for Teachers and Academic Researchers in the Sustainable Education Process

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Abstract:
This article explores children's natural curiosity about science and the factors that encourage their interest, drawing on the educational philosophy of Maria Montessori. It emphasizes the importance of hands-on, inquiry-based learning to foster children's interest in science. Special attention is given to children with special needs, explaining legal definitions and educational adaptations required for inclusive learning. The discussion emphasizes the need for equitable, stimulating science education that is accessible to all learners. The main objective is to present an initiative that introduces science to children with special needs through hands-on experiments in a model elementary school. Around 150 pupils from various adapted and special education programs participated in engaging, sensory-rich activities led by researchers from the Jožef Stefan Institute. The activity highlights the importance of integrating scientific values into inclusive education to improve learning equity and sustainability. It emphasizes the need for collaboration between educators and researchers in creating accessible and meaningful science experiences for all pupils.

Keywords: Inclusive education, Science, Experimental work, Natural sciences, Sustainable education process, Collaboration

1. Introduction

1.1. Children and science – Are children interested in science and what motivates them to be more interested in scientific topics?

According to Maria Montessori's theories, children are believed to have a natural interest in science (Montessori, 1995). Child's curiosity should be nurtured through hands-on, exploratory learning. Her observation was that children are instinctively drawn to understanding the world around them and science provides a way to satisfy this drive by engaging their senses. In Maria Montessori' s theories, children begin to take an interest in science during their school years. At this time, they begin to research tirelessly and ask questions because they want to know and understand something. This is the time when the abstract part of the child's mind is organised. During this time, children begin to ask questions that are often philosophical in nature (*e. g.* Why are leaves green? Why does the sun set and the moon rise in the evening? etc.) because their curious minds want to know and understand something (Montessori, 1995).

1.2. Who are children with special needs?

Children with special needs are defined in the *Placement of Children with Special Needs Act* (ZUOPP-1, 2011; ***Law 1***) as children with intellectual disabilities, blind and visually impaired children or children with visual impairments, deaf and hard of hearing children, children with speech and language disorders, physically disabled children, children with long-term illnesses, children with learning disabilities in certain areas, children with autistic disorders and children with emotional and behavioural disorders (***Law 1***).

Children who have been identified as having special needs require adapted implementation of education and training programmes with additional professional support or adapted education and training programmes or special education and training programmes. These children require adapted spaces and resources that meet the guidelines for adapted programme implementation (***Law 1***). The educational programme can also be adapted to enable children with special needs to acquire an equivalent standard of education by adapting the curriculum, organisation, methods of knowledge assessment and evaluation, methods of external knowledge assessment, progression and timetable of lessons (***Law 1***).

2. Science experiments in Roje Primary School

We wanted to bring science closer to children with special needs. As part of a technical day, we demonstrated some experiments to the pupils of Roje Primary School. The experiments were attended by children who attend the development department of the school's kindergarten, pupils who attend an adapted education and training programme and pupils who attend a special education and training programme (Roje Primary School, n. d.). Approximately 150 pupils attended the presentation: 6 from the school's kindergarten development department, 90 pupils attending an adapted education and training programme and 54 pupils attending a special education and training programme. Researchers from the Jožef Stefan Institute led an educational discussion while conducting scientific experiments. All experiments were designed so that pupils could participate, gain hands-on experience and relate the experiments to real-life situations (Jeran et al., 2024).

The session began with a stimulating discussion about air and its components (National Geographic, n. d.; National Oceanic and Atmospheric Administration, n. d.). More developed pupils eagerly participated in the discussion about the components of air and the methods of isolating them. Many of them already had knowledge of the gaseous composition of air. After this theoretical foundation, the most important components of air (nitrogen and oxygen) were illustrated by practical demonstrations.

All participants, including those with special needs, were particularly fascinated by liquid nitrogen, which made a remarkable first impression due to the smoke produced by the rapid condensation of water vapour around the cold liquid. All pupils also had the opportunity to see and observe liquid nitrogen up close. They were also encouraged to blow into the cold liquid to create a cold and refreshing mist (**Figure 2** (**c**)). Simple experiments were used to investigate the practical effects of the extremely low temperature

(-196 °C) (Liquid nitrogen, n. d.). Remarkable demonstrations was the observation of how a balloon deflates when immersed in liquid nitrogen and then re-inflates to its original size at room temperature – an illustration of how gases behave at different temperatures (**Figure 2** (**a**)). At room temperature, the air molecules inside the balloon move quickly and take up a larger volume. When the balloon is cooled with liquid nitrogen, the air molecules slow down as they lose heat. This leads to condensation and deflation of the balloon. If you shine a torch, you can also observe the liquefied air at the bottom of the shrunken balloon. When the balloon is warmed back up to room temperature, the air inside heats up, expands and the balloon returns to its original size (Jeran et al., 2024).

The Leidenfrost effect on the skin was used to illustrate the significant temperature difference between liquid nitrogen and the human body (Adda-Bedia et al., 2016). When liquid nitrogen briefly comes into contact with the skin, part of it evaporates immediately and forms an insulating layer of gas. The remaining liquid then rolls over this gas layer without direct contact. With prolonged contact, however, there is a risk that this gas layer will dissolve, which can lead to frostbite or more serious injuries. Suitable protective equipment is therefore essential when working with liquid nitrogen (University of Reading, 2023). You will need special gloves, as normal laboratory gloves can become brittle on contact with the cold gas, which can lead to skin ulcers. We have also demonstrated the effect of liquid nitrogen on these standard gloves, which has further emphasised their fragility under such conditions, as they become brittle and break under physical stress. To mimic the effect on biological material and to show young people the damaging effects of liquid nitrogen, we also demonstrated the freezing of green leaves in liquid nitrogen, which solidified and became like glass – the water in the cells turned to ice. These frozen leaves broke easily and showed the profound effect that low temperatures have on biological material. All pupils eagerly participated in this experiment and learnt first-hand about the effects and dangers of liquid nitrogen on biological matter (**Figure 2** (**b**)).

Building on these experiments, we discussed the topic of storing liquid nitrogen. We showed the large vessels (dewar flasks) that we used to transport the liquid nitrogen (University of Reading, 2023). These vessels are well insulated to prevent heat exchange and loss of nitrogen. However, They are not sealed, as closing the container would lead to a rapid increase in gas pressure inside the container (University of Reading, 2023). To demonstrate this problem, we have shown the consequences of trapping a small amount of liquid nitrogen in a plastic bottle with a rubber stopper (Jeran et al., 2024). The trapped liquid nitrogen boils continuously, causing the gases in the sealed container to expand and the pressure to rise. When the liquid nitrogen turns to gas, the volume increases more than a hundredfold, generating enough force to eject the stopper. In an alternative demonstration, a bottle with a rubber stopper was used, pierced by a thin tube through which the nitrogen gas quickly escapes and forms a large cloud. This experiment is often referred to as a "nitrogen fountain" (**Figure 2** (**e**)).

We have then moved on from physical changes in matter to chemical reactions and transformations. Fire is a chemical reaction that everyone recognises and which is seen as an important step in human development (New Scientist, n. d.; Stauffer et al., 2008). In a discussion with more verbal pupils, we summarised that fire is a chemical reaction in which fuel and oxygen are converted into carbon dioxide, water and heat, creating new, more stable products. However, this simplified explanation does not do justice to the complexity of this reaction, in which there can be many different products, depending primarily on the fuel and the availability of oxygen (Stauffer et al., 2008). The latter is particularly important as it can lead to incomplete combustion and material residues. We have demonstrated the different cases of combustion by burning different materials – dried bread, cotton, nitrocellulose. In the first case, dried bread does not really burn well when we try to set it on fire. The participating pupils realised that this material does not burn well. At school we are taught about the "fire triangle", three things that are needed for a fire: fuel, oxygen and heat (Palcon, n. d.). In this experiment we provided all three, but sometimes they are not all available in sufficient quantities. We modified this experiment by adding more oxygen to the mixture. To do this, we condensed air from the atmosphere onto a metal cone filled with liquid nitrogen. The condensed air contained a higher proportion of oxygen due to its higher boiling point. As soon as we had collected enough oxygen, we soaked the dried bread in it and then set it alight. In the first experiment, the dried bread did not burn, even though it was constantly lit with a lighter, while in the second experiment the fire burned very brightly and independently. We explained to the participants that more oxygen leads to a more complete reaction. We also backed this up with two other fire reactions, one with normal cotton (celulose), the other with nitrocellulose cotton. Whilst cotton burns quite well, it leaves a solid residue, indicating incomplete combustion. We repeated the same experiment with nitrocellulose cotton, which burned almost immediately and astonished the audience (**Figure 2** (**h**)). This particular cotton contains nitro groups (-NO_2) which act as an oxidising agent – a 'source' of oxygen (Tramšek et al., 2023). Coming back to the fire triangle (**Figure 1**), this means that we have both the fuel and the oxygen in a single compound, the only requirement to start a fire is heat (Palcon, n. d.). This is a typical feature of compounds used as explosives, of which nitrocellulose is one. We have also observed that no solid residues are produced in this reaction, as the solid is completely converted into gaseous products. With these experiments, we have shown the influence of oxygen on both the speed of the reaction and its completeness.

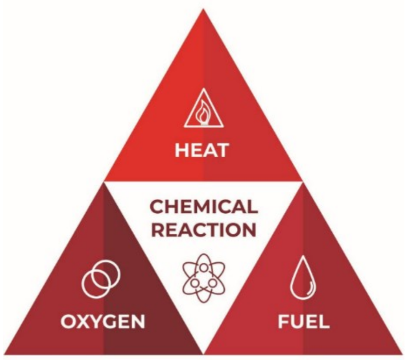

Figure 1. Oxygen, heat, and fuel are frequently referred to as the "fire triangle" (Palcon, n. d.).

We have continued the visually attractive experiments by showing two different flame reactions. As the name suggests, this is a combustion reaction, but it involves different cations that give the flame a unique colour. In the first example, we poured a solution of spirits into a glass bottle, closed it, shook it well and quickly poured out the contents. The empty bottle contained only spirit vapours, which quickly ignited and resulted in a slow-moving orange wall of flame. The orange colour comes from the sodium Na^+ from the salt, which is excited by the flame and emits the orange light when it releases the energy (Tramšek et al., 2023). As sodium is very common in nature, most fires have an orange colour. A similar experiment was carried out in a flask by placing aluminium foil in a solution of hydrochloric acid and copper(II) sulphate (Fleming, 2014). The aluminium reacted quickly with the hydrochloric acid and produced flammable hydrogen gas. This gas was then ignited, producing a bright, swirling blue-green flame that burned until all the aluminium was consumed. As in the previous experiment, the metal cation, in this case copper, produces the distinct colour when excited by the fire. We then explained that this effect is common with fireworks, which contain many different materials that produce different colours.

Having recognised that light can be produced by means other than fire, we have turned our attention to other luminescence reactions. The classification of luminescence is usually based on the nature of the emitted energy. Bioluminescence, which is often observed in natural systems, is often the enzymatic catalysis of the oxidation of a substrate (e.g. the oxidation of luciferin catalysed by luciferase in fireflies) (Marinko et al., 2024). Photoluminescence comprises two phenomena: fluorescence, which occurs under continuous energy input (usually radiation), and phosphorescence, which can persist even after the energy source is removed. We have introduced the fluorescence of various dyes, including fluorescein, a component of fluorescent markers (**Figure 2** (**f**)). Chemiluminescence, the generation of electromagnetic radiation as light through a chemical reaction, was illustrated using the reaction between luminol and hydrogen peroxide (Jeran et al., 2020).

After the light reactions, we next investigated more colourful transformations. We carried out a reaction in which a lollipop was dissolved in a sodium hydroxide solution with potassium permanganate (Prolongo & Pinto, 2018). As the sugar of the lollipop dissolved, we observed a series of colour changes, each corresponding to a different oxidation state of the manganese (Prolongo & Pinto, 2018). This series of redox reactions involves the continuous transfer of electrons from the glucose to different manganese compounds, with each step in this chain manifesting itself in a distinct colour change (**Figure 2** (**g**)). Manganese lends itself well to this demonstration due to its numerous stable oxidation states (from +2 to +7), each of which has a unique colour (Prolongo & Pinto, 2018; Jeran et al., 2024).

In the following experiment, we investigated several simultaneous chemical changes (Royal Society of Chemistry, n. d.; Liu et al., 2021). First, we prepared a solution of calcium chloride and fluorescein in a large beaker. Then we used a syringe to introduce a steady stream of sodium alginate solution. The viscous alginate quickly reacted with the calcium ions and formed a solid, string-like compound. As the original solution contained fluorescein, this alginate string also exhibited fluorescent properties (Royal Society of Chemistry, n. d.). Interestingly, the fluorescence of the filament disappeared when it was cooled with liquid nitrogen, demonstrating that there is a significant temperature effect even with non-biological materials.

Finally, we performed a straightforward reaction with ferric chloride ($FeCl_3$) and potassium thiocyanate (KSCN) (MEL Science, n. d.). We asked volunteers to draw on paper with a cotton swab soaked in pale orange $FeCl_3$ solution. After they had completed their drawings, we sprayed them with KSCN solution, which resulted in a dark red image. This colour change resulted from the rapid reaction between $FeCl_3$ and KSCN, producing the more stable, red-coloured $Fe(SCN)_3$ (Jeran et al., 2024). Given the simplicity of this experiment, all pupils were encouraged to try it out for themselves (**Figure 2** (**d**)).

Figure 2. Observing the properties of liquid nitrogen: (**a**) interaction of liquid nitrogen with air from an inflated balloon, (**b**) freezing plant tissue in liquid nitrogen and testing for brittleness, (**c**) participants blowing into a container of liquid nitrogen and (**e**) nitrogen fountain – gas escaping through a hole. (**d**) Artistic creation with chemical reactions – reaction between iron trichloride and potassium thiocyanate, the product is a red colored complex. (**f**) Demonstrating a series of chemiluminescence reactions to simulate the phenomenon of light in fireflies and jellyfish. (**g**) Observation of the oxidation states of manganese with a lollipop in dilute aqueous sodium hydroxide solution. (**h**) Ignition of nitrocellulose cotton.

3. Conclusion

The integration of scientific values into inclusive education represents both a profound challenge and a critical opportunity for educators and academic researchers. Incorporating these values, such as objectivity, critical inquiry, and evidence-based practice, increases the effectiveness and equity of educational approaches. Teachers must constantly adapt to the diverse needs of pupils while maintaining rigorous academic standards, and researchers must support this process through interdisciplinary collaboration and innovation. Ultimately, incorporating scientific values into inclusive education is essential to promoting a more sustainable, equitable and resilient education system that leaves no learner behind. Such approaches are important for both educational progress and the academic community, and we will continue our work.

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Conflicts of Interest: The authors declare no conflict of interest.

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