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The Development of Science Process Skills and Content Knowledge with Inquiry Boxes in Early Childhood Education

Nika Golob*[1] and Vanja Ungar[2]

This paper aims to investigate the systematic use of an inquiry-based learning approach in science by using inquiry boxes for preschool children. We prepared four thematic inquiry boxes for the areas of magnetism and buoyancy, separation of substances, weighing objects, and the investigation of substances. The research sample consisted of twenty children aged four to five years. Ten children from the experimental group explored the material using the photo-type instructions on the instructional cards over a period of four weeks. Comparative test results for the control group children show that the experimental group children progressed both in content knowledge and in better-developed science process skills. We find that children develop autonomy in science process skills such as classifying, ordering, and weighing through prepared and guided inquiry with the help of the inquiry boxes. In doing so, children show increasing autonomy within each set of tasks that develop the chosen science process skill. In this manner, science practices with inquiry boxes allow children to build on science content knowledge. They can apply the skills they have learned through inquiry boxes to new knowledge instead of teaching science processes as isolated skills. This approach of individually guided inquiry by children using thematic inquiry boxes is therefore recommended as a proven didactic tool for developing science process skills and content knowledge.

Keywords: development of science process skills, inquiry boxes, content knowledge, early childhood education

1 *Corresponding Author. Faculty of Education, University of Maribor, Slovenia; nika.golob@um.si.
2 Blaže in Nežica Kindergarten/Vrtec Blaže in Nežica, Slovenska Bistrica, Slovenia.

Razvijanje spretnosti naravoslovnih postopkov in vsebinskega znanja z raziskovalnimi škatlami v predšolskem izobraževanju

Nika Golob in Vanja Ungar

Namen članka je raziskati sistematično uporabo raziskovalnega učenja v naravoslovju z uporabo raziskovalnih škatel za predšolske otroke. Pripravili smo štiri tematske raziskovalne škatle s področij magnetizma in vzgona, ločevanja snovi, tehtanja predmetov in preučevanja snovi. Raziskovalni vzorec je predstavljal dvajset otrok, starih od 4 do 5 let. Deset otrok iz eksperimentalne skupine je v štirih tednih raziskovalo material iz raziskovalnih škatel s pomočjo slikovno-fotografskih navodil na delovnih karticah. Rezultati primerjalnih testov za otroke iz kontrolne skupine kažejo, da so otroci iz eksperimentalne skupine napredovali v vsebinskem znanju in tudi v bolje razvitih spretnostih naravoslovnih postopkov. Ugotavljamo, da otroci s pomočjo pripravljenega in vodenega raziskovanja z raziskovalnimi škatlami razvijajo samostojnost pri spretnostih naravoslovnih postopkov, kot so: razvrščanje, urejanje in tehtanje. Pri tem otroci kažejo vedno večjo samostojnost v vsakem sklopu nalog. Naravoslovna dejavnost z raziskovalnimi škatlami otrokom omogoča nadgradnjo znanja naravoslovnih vsebin. Spretnosti, ki so se jih naučili s pomočjo raziskovalnih škatel, lahko uporabijo kot novo znanje, na novem primeru, namesto da bi naravoslovne postopke urili kot izolirane spretnosti. Pristop individualno vodenega raziskovanja otrok z uporabo tematskih raziskovalnih škatel je tako priporočljivo in preizkušeno didaktično orodje za razvijanje spretnosti naravoslovnih postopkov in vsebinskega znanja.

Ključne besede: razvoj spretnosti naravoslovnih postopkov, raziskovalne škatle, vsebinsko znanje, predšolsko izobraževanje

Introduction

Inquiry-based education is student-centred learning and teaching in which students learn by adopting inquiry methods. It also acts as an educational strategy that enables students to acquire knowledge with methods similar to those used by professional scientists or in a way akin to that adopted by scientists in practice. For example, science-oriented, inquiry-based learning involves supporting students as they gain science knowledge through science experiments rather than from teachers (Hong et al., 2020). It is crucial that children in early childhood education (ECE) learn in such a way that they can transfer their knowledge to different problems, settings, and times (Klahr & Chen, 2011).

After considering a meta-analysis of research in the field of early science, Jirout and Zimmerman (2015) establish that in their play, even very young children conduct 'experiments' to discover causal links. Similarly, children aged six successfully recognise experimental designs as valid and meaningful or not. Children aged five can identify patterns in evidence, interpret the usefulness of evidence, and understand how evidence relates to a hypothesis. While young children show well-developed science process skills in extremely simple science tasks, older primary school children and adults may have difficulty with more complex tasks, even though they involve the same types of skills. These results suggest that young children do not learn individual skills of science inquiry (discovery using the scientific method) but, over time, develop skill sets that enable them to answer science questions, find ways to gather information in response to these questions, and observe and infer evidence to learn about the unknown. In contrast, data on children's curiosity show that it fades with age, although it is present in young children and remains present at least through the early primary school years (Jirout & Zimmerman, 2015).

Similarly, Siry and Max's (2013) research reveals that from an early age, children have the capacity to 'conduct investigations, explain their observations and plan new investigations' (p. 899). Likewise, Kiel (2011) confirmed that children develop basic scientific methodological skills such as integrating information and drawing conclusions; Gopnik (2012) found that they are capable of forming abstract and causal structures from a very young age. The authors argue that such skills, which are important for inquiry and discovery, can be developed if children are given the opportunity to systematically explore and make sense of the surrounding world. Byrne (2016) added that it is possible to develop inquiry-based learning requirements in early childhood education, including wondering, experimenting, gathering evidence, and using evidence to draw conclusions.

Fragkiadaki et al. (2023) determined that motivation for learning science concepts can begin in infancy in educational settings. While it is impossible to determine young children's conceptual understanding from their speech, it is possible to observe their actions and see how they engage in play and solve problems. These authors pointed out that while studying children, we must also study the conditions teachers create in their educational programmes, which is a dialectical relationship. Their research leads them to suggest that they 'come together for deep conceptual development of the child in science, so we continue to create these conditions for scientifically engaging them in their world systematically over time' (p.18).

It is also important to foster children's autonomy during active inquiry, as Devjak et al. (2021) noted. Among the factors that help promote children's autonomy, they list the educator taking the children's perspective, supporting children's self-initiative, and enabling them to make decisions and solve problems (Devjak et al., 2021). The positive impact of STEM (Science, Technology, Engineering, and Mathematics) activities (Akcay Malcok & Ceylan, 2021; Dilek, 2020), project-based science education for preschool children on problem-solving ability is referred to in many contemporary research studies (Can et al., 2017). In addition, the knowledge and interest of preschool and kindergarten children in science is an indicator of their later success in school STEM (Clements & Sarama, 2016).

Science process skills

Science process skills (SPS) are physical and mental skills in collecting information and organising it in several ways. SPS are used to process new information in concrete learning. They can also build new concepts and new understandings of science (Charlesworth & Lind, 2012). SPS are the skills that scientists use in their research (McComas, 2014). There are two categories of SPS: basic and integrated. Basic SPS include observing, classifying, ordering, measuring, inferring, predicting, and communicating. Integrated SPS involve identifying and controlling variables, formulating and testing hypotheses, interpreting data, defining operationally, experimenting, and constructing models (McComas, 2014; Saçkes, 2013). Charlesworth and Lind (2012) defined SPS as competencies used during the production of science knowledge while regulating the ensuing knowledge and also analysing and solving any problems occurring in the process of producing science knowledge.

In the Slovenian Kindergarten Curriculum (Ministry of Education, Science and Sport of the Republic of Slovenia, 1999), specifically in the text for the

'Nature' activity area, there are guidelines for activities to help children develop SPS, worded as follows: observing with all the senses, comparing, ordering, and classifying substances, objects, living beings and phenomena in nature and the environment. It is recommended that while classifying, the educator should encourage the child to use their own criteria and to comment on and explain the choices made. Several activities are also suggested to develop experimentation (through a science experiment or test).

Early childhood and science educators agree that children need to be able to do science. According to Larimore (2020), there is disagreement over what it means for young children to do science in a meaningful way. Early childhood educators typically refer to doing science in terms of 'process skills' (Jirout & Zimmerman, 2015). While process skills are components of science practices, they should not be our ultimate goal when considering how children do science. SPS, such as observation and prediction, have been theorised as skills that can be developed independently of content knowledge.

In contrast, science practices integrate the knowledge and skills needed to 'do' science. Much research in education for children from kindergarten through twelfth grade (K-12) shows that learning skills in isolation does not help children apply them meaningfully in other contexts (National Research Council, 2007). Practices are linked to knowledge, and not all process-related skills are equal in scope. A prediction can be based on prior knowledge or experience, yet it need not – it can simply be a guess, as Larimore (2020) explains. This means that science practices allow children to use their previous knowledge to engage with natural phenomena to gain new knowledge about the world rather than developing isolated skills (Larimore, 2020).

As an SPS, experimenting is more complex than prediction. Experimenting has a different meaning than the process skill of 'observation', Larimore (2020) claims. A biochemist holds an entirely different understanding of an experiment than is appropriate for early childhood education (ECE). Suppose in ECE we aim to teach a child to design a science experiment taking the dependent and independent variables into account. In that case, we must be aware that this is not the only traditional form. In some sciences, other methods of experimentation have been developed to answer research questions or test hypotheses. Planning and investigating are a practice in which pre-schoolers can easily participate. Young children can observe phenomena under a variety of conditions (Larimore, 2020) that are simple and repeatable.

SPS development in context is also discussed in Dilek (2020). Providing context is the only way to ensure a child acquires new knowledge through a concrete experience. With such a meaningfully designed science experience, children develop process skills that are important in their daily lives. Young children's natural curiosity is crucial for learning science skills, and they not only learn skills but also build on a set of skills over time (Jirout & Zimmerman, 2015; Kuru & Akman, 2017). Moreover, these skills in the early years are also the best predictors of children's science achievement in their subsequent grades since their development gradually progresses with age (Saçkes, 2013). There is also a positive relationship between children's creative thinking and SPS scores (Yildiz & Guler Yildiz, 2021). Therefore, researchers suggest that inquiry-based activities should be implemented in ECE.

Science inquiry not only includes SPS but also refers to the combination of these skills with scientific knowledge, scientific reasoning, problem-solving, and critical thinking in social settings (Vartiainen & Kumpulainen, 2020). The literature in this area gives an insight into young children's diverse and significant abilities in science. Therefore, the Slovenian early childhood education curriculum needs to be updated in the field of science because its practical implementation does not reflect modern findings and the understanding of the early development and learning of toddlers/children, as was noted by Umek (2021). She further stressed that the curriculum should pursue long-term objectives like the development of an autonomous, responsible, critical, and creative individual (Umek, 2021). If implemented appropriately, science inquiry can develop these dimensions of a person's activities.

Improvement is also essential in pedagogical content knowledge, given that it is a contributing factor for many teachers who tend to avoid inquiry experiences in their classrooms (Gropen et al., 2017). Accordingly, an important role in the learning process of future educators is played by their involvement in the preparation and use of materials for children's inquiry (Eckhoff, 2017). The importance of the continuous professional development of educators, along with reflection, self-evaluation, and evaluation of their teaching practice, was also highlighted by Umek and Drvodelić (2021). A positive impact on changing one's own teaching practice is reported by Blannin et al. (2020), who concluded from their research that collective and self-reflective inquiry enabled teacher-researchers to understand and improve upon the practices in which they participate and the situations in which they find themselves. The importance of future teachers' reflective thinking within various courses of their study is discussed by Devjak and Krumes (2017), who emphasise that even university teachers should embrace reflective thinking by becoming critically reflective practitioners.

The theoretical background and existing research suggest that SPS and content knowledge play a crucial role among older pre-schoolers (aged 3–6) when engaged in inquiry learning facilitated by educators.

Inquiry Boxes and Content Knowledge

Skribe-Dimec (2010) introduced the concept of inquiry boxes (IBs) in Slovenia as a didactic tool for primary science education. IBs are designed to foster science literacy by engaging children in autonomous science inquiry through carefully prepared thematic collections of materials and guided inquiry instructions. In her book *Raziskovalne škatle: učni pripomoček za pouk naravoslovja* [Inquiry Boxes: A Teaching Tool/Aid for Science Lessons] (Skribe-Dimec, 2010), the author presents some ideas for a thematic collection of objects and instructional cards with written instructions for guided inquiry. The instruction is usually a simple task to develop SPS with a prepared collection of materials. Following instructions, the child investigates a collection of materials by classifying, comparing, ordering, and measuring objects, performing simple tests with objects, making predictions, and making reports. The inquiry is thus divided into a series of smaller tasks that the child is able to complete using the instructions on the instructional cards, which are a partial answer to the broader research question hidden in the IB thematic field. The positive role of dividing the problem into a set of smaller ones in the domain of science in early childhood is discussed by Fridberg et al. (2020).

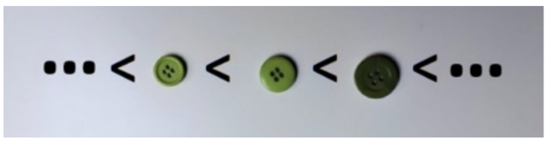
Numerous research projects conducted by pre-primary and primary education students in their final theses (e.g., Brbre, 2012; Flego, 2015; Kopič, 2021; Kvas, 2019; Lamovšek, 2015; Perko, 2008; Smiljan, 2021; Šenica, 2022) at Slovenian universities have explored IBs. Most of these studies focus on practical validation through individual observation of children working with one IB (thematically varied based on the study). The researchers mainly assess children's autonomy in understanding instructions and their success in task-solving, thereby evaluating the effectiveness of the prepared IBs. Motivated and successful autonomy is often observed, particularly in tasks involving simpler SPS.

However, none of the mentioned studies monitored the progress of content knowledge or provided an overview of SPS development when children engage with various thematically different IBs over an extended period. As a result, the present study aims to create four thematically different IBs for fostering autonomous inquiry in pre-schoolers and examine the impact of these boxes on content knowledge and SPS development.

As presented below, we designed and created four inquiry boxes in the thematic fields of magnetism and buoyancy; separation of substances; weighing; and investigation of substances.

The instructional cards, as named by Osredkar and Skribe-Dimec (2009, 2010), were adapted in our IBs for preschool children who cannot yet read, with photo-type instructions that include photographs of the objects collected in the box. A similar approach using photography was also employed by Jeffries (2011). As part of photo-type instructions, the photographs were supplemented with symbols to help the child understand the instructions on the instructional card. According to Kambouri and Pieridou (2016), symbols can help explain abstract science concepts. Figure 1 is an example of one of the IB instructional cards, combining a photograph and symbols. We identified a prioritised SPS for each photo-type instructional card task. (For more on the design of an IB for preschool children, see Golob (2020)).

Figure 1
Example of a photo-type instructional card from the Separation of Substances IB, using photography and symbols for ordering by size and sequence



The **Nuts and Bolts** IB (adapted from Lamovšek, 2015) includes the thematic area of magnetism and buoyancy, in which children learn about nuts and bolts from different materials (metal, plastic, wood), check magnetic properties and buoyancy, make predictions based on experimentation, order by size, etc. The content of the IB is presented in Figure 2a.

When preparing the material, we considered the findings of Kalogiannakis et al. (2018) and Paul (2018), who established that pre-schoolers have difficulty understanding that not all metals are attracted by magnets. We, therefore, chose only those metal nuts and bolts that are attracted by magnets and hence planned only a basic experience of magnetism for the children.

By preparing the materials in the IB, we planned for a child to generalise, based on the experiment (Hsin & Wu, 2011), that metal nuts and bolts sink, whereas plastic and wooden ones float. Explanations using the density of a material, which involves mass and volume, are still too complex for many 11-year-olds (Smithenry & Kim, 2010). See the Appendix for the list of tasks as shown by the eight photo-type instructional cards.

Figure 2
a: *Contents of the Nuts and Bolts IB;* ***b***: *Example of a photo-type instructional card from the Separation of Substance IB by sieving;* ***c***: *Contents of the Weighing IB (a Styrofoam ball, a ping pong ball, a super ball, various marbles, instructional cards, and a balance scale)*

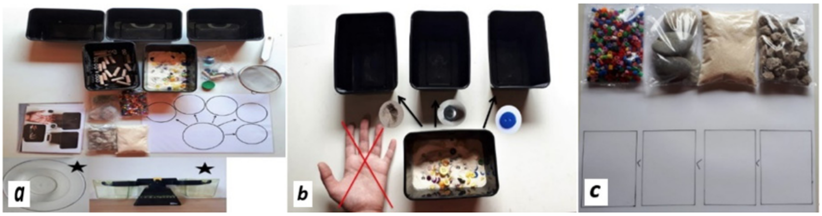
Young children usually have a limited understanding of the properties of materials; colour and hardness generally are understood (Prieston & Love, 2021). By preparing the materials in the **Separation of Substance** IB, we aim to extend children's basic descriptions of the properties of materials to include the size of their particles. According to Abdo (2022), very few studies have focused on chemistry and how more chemical content could be transferred to a preschool environment. One example is separation methods like filtering or sieving (Abdo, 2022). An example of a sieving task is shown in Figure 2b. See the Appendix for the list of tasks as shown by the eight photo-type instructional cards.

The **Weighing** IB aims to teach children how to use a balance scale. Figure 2c shows the contents of the IB. Children compare the size and weight of different balls. The concept of weight is easier for children to understand than the concept of mass, which is still too abstract for them (Bar et al., 2016). The concept of weight is best introduced to children through their own experience if two objects of different weights are placed in the child's hand, and the child compares which one pushes a hand more downwards. A balance determines mass by balancing an unknown mass against a known mass. When designing the **Weighing** IB, we deliberately chose balls of different sizes and materials, with some smaller balls being heavier than the larger ones. This was to encourage children to realise that weight and size are not necessarily linked. Similar activities are also described in Bajd et al. (2013). See the Appendix for the list of tasks as shown by the nine photo-type instructional cards.

The fourth IB, **What Do You Know About A Substance?**, tests and consolidates the content knowledge acquired and the SPS of the first three IBs. Figure 3a shows its contents. In this IB, children separate a substance using a limited range of processes. They must apply their content knowledge in different situations and practise SPS in more complex tasks (see Figure 3b), as in the instructions in the first three IBs.

Similarly, the sizing task requires ordering equally sized packages of substance according to the size of particles, as shown in Figure 3c. The weight-ordering task is also more challenging, as the child weighs packages of substance identical to those in Figure 3c. See the Appendix for the list of tasks as shown by the five photo-type instructional cards.

Figure 3
a: *Content of the What Do You Know About A Substance? IB;* ***b***: *The What Do You Know About A Substance? IB photo-type instructional card for separating a mixture of semolina, metal nuts, and plastic buttons without handling the items;* ***c***: *The What Do You Know About A Substance? IB photo-type instructional card for ordering equally sized packages of substances by particle size*



With regard to the research aims, the following research questions (RQs) were addressed:

RQ1: Does inquiry learning through IBs influence the progress of 4- to 5-year-olds' content knowledge?

RQ2: Does the child develop SPS when inquiring by using several different IBs in sequence?

Methods

Participants

The study sample is a non-randomised sample from a specific population of twenty children aged 4–5 years attending the same kindergarten with a publicly approved ECE programme in Slovenia, which includes children from both urban and rural settings. Ten children, randomly selected from the sample, were included in the experimental group working with the IBs. The other ten children were placed in the control group. In both groups, half were boys, and half were girls.

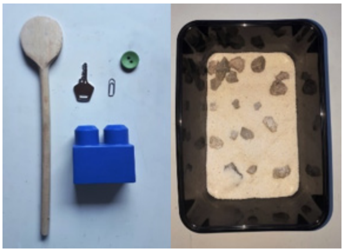
Having both a control group and an experimental group in a study is crucial for establishing causality and improving the validity of research findings. It allows researchers to assess the progression without any new intervention, which helps identify if the observed changes result from the tested IBs. The educator ensures the absence of magnets, intentional buoyancy experiments, and balance scales in kindergarten. The use of sieves in the sandpit is limited to free play activities only and is part of the regular daily routine. As both the control and experimental groups are drawn from the same kindergarten setting and have been selected through random sampling for this study, we consider the two groups to be comparable.

Instruments

The data for the study were collected using a qualitative data collection technique, specifically individual testing and observation, and recording using an observation protocol. To *test* the content knowledge, semi-structured pre- and post-interviews were designed to individually test children's knowledge of the magnetism, buoyancy, weighing and separation of substances. The interview consisted of four sets, each related to its own domain, and we prepared the same collection of materials for each set, as shown in Figure 4. The collection consists of five objects: a metal key, a metal paper clip, a wooden spoon, a small plastic brick, and a plastic button. Without testing anything, the children predicted what they thought the magnet would attract and, in the second set, which objects would float or sink in the water. For buoyancy, we also asked them for a reason: why do they think the object will float or sink? Their answers were duly recorded. If the children correctly predicted all five objects, they received five points. The magnet sticks to the metal key and the metal paper clip. A wooden spoon and a plastic cube do not sink in water.

Figure 4

A collection of materials for testing knowledge of buoyancy and magnetic properties (left) and a mixture for testing knowledge regarding possible ways to separate mixtures (right)



For the third set of tests, children were offered a mix of semolina and small pebbles and asked how they could most quickly separate the mixture (Figure 4, right) into two groups. The question was how (i.e., with what) would you make a separate pile of pebbles and semolina in the fastest way from a mix of the two materials? We wrote down the children's answers.

For the fourth set, we showed the children a child's balance scale (Figure 3a, marked with a star) and asked if they knew what it was and for what it was used. We asked the children whether they knew it was a weighing scale and how they would determine which of the two objects in the collection was heavier.

If they showed or described that the scale tipped downwards for a heavier object, we recorded that the child knew how to use a balance scale, but we did not tell them if they had solved the problems correctly.

The research employs a guided inquiry learning educational strategy. By using open-ended materials in the IBs, we stimulate children's curiosity, wonder, and interests, which serve as a vital starting point for the inquiry process. The children in the experimental group were introduced to basic IB work during the introductory phase by presenting prepared materials, photo-type instructional cards, and the topic of inquiry. The Preschool Inquiry Cycle, adapted from Trundle and Smith (2017) and tailored to the child's stage of development (Ramanathan, 2022), comprises the following phases: a) Play (engage, notice, question, wonder); b) Explore (predict, observe, record data); c) Discuss (construct, reflect, provide explanations, draw conclusions, develop new questions).

During the play phase, children work individually with the IB, allowing them to play with the materials freely, become familiar with the content, and express curiosity and engagement. The teacher then guides them to use photo-type instructional cards, which present open-ended questions and guided inquiry prompts, promoting the development of scientific process skills (SPS) and content knowledge.

The exploration phase involves making predictions, conducting unexpected observations, manipulating objects, taking measurements, classifying based on different characteristics, conducting experiments, and using various other SPS.

Although not planned and monitored as a social interaction in this study, the discussion phase is included in the subsequent inquiry cycle with another IB as a cognitive process. In the following IB, some of the previously introduced SPS are further developed, and specific science knowledge is confirmed with new examples. This allows the child to draw conclusions, provide explanations, or develop new questions suitable for their stage of development. For detailed information about the content of IBs, please refer to the section 'Inquiry Boxes and Content Knowledge'.

The children's individual work with the prepared IBs in the experimental group was closely monitored by their educator through observation and recording using an observation protocol. A table was used for entering the *observations*. For *each task* in the IB, the educator recorded a child's degree of success and autonomy. *Successful (value 1)* means that the child solved the task correctly, and *unsuccessful (value 0)* means they were unable to solve the task correctly. *Autonomous (value 3)* means that the child solved the task on their own, without needing help. If the child has expressed a need for help in understanding an instruction or task by gesture or word, it has been offered. If non-verbal help was sufficient for the child to continue the activity, it was recorded as a value of 2 on the autonomy scale. An example of *non-verbal help (value 2)* is a finger pointing in the direction of order, pointing to a tool that could help the child or pointing to a symbol. *Verbal help (value 1)* was represented by the educator asking a question, explaining the symbols on the instructional card, guiding the child through thinking, or giving complete instructions for a task. Moreover, in helping children, the educator did not tell the children the solution to the task but merely non-verbally or verbally explained the instructions given for each task on the photo-type instructional card. Sometimes, the educator just reads the text written on the back of a card.

The development of a test instrument for assessing children's knowledge is based on the subject-specific research already explained in previous chapters (Abdo, 2022; Bar et al., 2016; Friedberg et al., 2020; Hsin & Wu, 2011; Jeffries, 2011; Kambouri & Pieridou, 2016; Lamovšek, 2015; Paul, 2018; Preston & Love, 2021; Smithenry & Kim, 2010). The validity of the prepared materials (the IBs and testing materials) was ensured by expert reviews (checking the performance of prepared materials to determine if they correspond to the expected results of the experimentation) and by pilot testing.

Objectivity was ensured by providing detailed instructions to the educator of these children, the one who carried out observations of the children working with the IBs. Evaluation of the children's answers during the test (Test 1 and Test 2, as shown in Figure 9) was performed by the authors of the study without subjective judgment. Data anonymity was guaranteed for research purposes while processing the data.

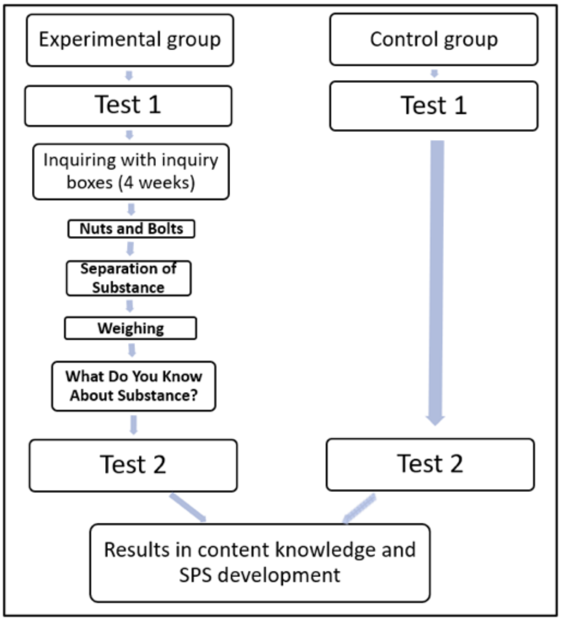
Before collecting the data, consent forms were also distributed to all participating parents of the children to be observed. The requisite permissions were obtained regarding the observation of participant children for this research.

Research Design

Twenty children from the same kindergarten were randomly divided into two gender-matched groups. Each child experienced individual testing (Test 1 in Figure 5) using semi-structured content knowledge interviews. The results were continuously recorded. The testing was conducted in a separate, quiet room, with each session lasting 10 minutes.

Figure 5

Research Process



Over the next four weeks, the children in the experimental group engaged in inquiry activities with the materials provided in the IBs. They completed the assigned tasks indicated on the instructional cards in a separate room within the kindergarten at various times of the day. All ten children in the experimental group individually tried out the Nuts and Bolts IB, followed by the Separation of Substance IB. On average, each child spent 25 minutes working on each IB. Over four weeks, all ten children interacted with all four IBs in the same order as presented here in the study (see Figure 5). The educator, who received proper training in using the IBs and instruments, conducted observations of the children while they worked with the IB and recorded the observations using the observation protocol.

After their sessions with the IBs, the children were again tested (Test 2 in Figure 5) using the same semi-structured interview. We tested all the children, both in the experimental and the control groups. The results were processed descriptively and presented in tables and figures according to research questions.

Results

Progress with content knowledge

The results of the experimental group testing are shown in Table 1. The experimental group made inquiries using all four IBs after the first test. Table 2 presents the results for the control group.

Table 1

Knowledge of the experimental group children in Test 1 and Test 2 (f_{max}= 5)

Child / Correct answers	Magnetism		Buoyancy				Weighing		Separation of a substance	
	Test 1	Test 2	Test 1		Test 2		Test 1	Test 2	Test 1	Test 2
	f	*f*	*f*	Reason for buoyancy	*f*	Reason for buoyancy	Familiarity with a balance scale		Separation method for a mixture of semolina and pebbles	
A	4	5	0	Mass	3	Material	No	Yes	Handpick	Sieve
B	1	5	1	Mass	5	Material	No	Yes	Handpick	Sieve
C	2	5	2	Mass	5	Material	No	Yes	Handpick	Sieve
D	2	5	0	Mass	4	Material	No	Yes	Sieve	Sieve
E	5	5	2	Mass	5	Material	No	Yes	Handpick	Handpick
F	4	5	3	Material	5	Material	No	Yes	Sieve	Sieve
G	3	5	2	Mass	5	Material	No	Yes	Handpick	Sieve
H	4	5	1	Mass	4	Material	Yes	Yes	Sieve	Sieve
I	5	5	0	Mass	4	Material	No	Yes	Handpick	Sieve
J	1	3	0	Mass	2	Mass	No	Yes	Handpick	Handpick

Table 2
Knowledge of the control group children in Test 1 and Test 2 ($f_{max} = 5$)

	Magnetism		Buoyancy				Weighing		Separation of a substance	
Child / Correct answers	Test 1	Test 2	Test 1		Test 2		Test 1	Test 2	Test 1	Test 2
	f	*f*	*f*	Reason for buoyancy	*f*	Reason for buoyancy	Familiarity with a balance scale		Separation method for a mixture of semolina and pebbles	
K	1	2	0	Mass	0	Mass	No	No	Handpick	Handpick
L	1	1	0	Mass	0	Mass	No	No	Handpick	Handpick
M	2	2	0	Mass	1	Mass	No	No	Handpick	Handpick
N	4	5	2	Mass	2	Mass	Yes	Yes	Sieve	Sieve
O	3	3	3	Mass	3	Mass	No	No	Sieve	Sieve
P	1	1	2	Mass	2	Mass	No	No	Handpick	Handpick
R	0	0	1	Mass	1	Mass	No	No	Handpick	Handpick
S	1	1	1	Mass	0	Mass	No	No	Handpick	Handpick
T	2	1	0	Mass	1	Mass	No	No	Handpick	Handpick
U	5	5	3	Mass		Mass	Yes	Yes	Sieve	Sieve

From *Table 1*, in the area of knowledge about *magnetism*, we see that two children in the experimental group correctly classified all five objects in Test 1 according to whether they were attracted by magnets or not. In Test 2, nine children correctly classified all five objects. Nine children out of 10 (90%) scored better than in Test 1. Children in the control group (*Table 2*) scored similarly to children in the experimental group (*Table 1*) in Test 1.

Comparing the results of the experimental group (*Table 1*) with the control group (*Table 2*) in the area of *buoyancy*, both groups showed similar patterns in Test 1. In both groups, no child answered correctly for all five objects. Like the experimental group, all children in the control group attributed buoyancy to the object's mass (heavier objects sink, lighter objects float on water) (*Table 2*).

In Test 2, five children in the experimental group correctly classified all five objects, and only one child classified less than half correctly. Nine children attributed differences in buoyancy to the material, while there was no change in the control group (buoyancy is mass-dependent). None of the children in the control group correctly classified all objects in Test 2.

Only three children knew what a balance scale was and what it was used for (*Table 1* and *Table 2* combined) in Test 1 in the *weighing* set. They were also able to say how they intended to determine which of the two objects was heavier. Other children did not know what the object in front of them was or why it might be used. In Test 2, all children in the experimental group knew what a balance scale was and what it was used for (*Table 1*). They were also able to identify the heavier of the two objects. The knowledge of the control group in Test 2 remained unchanged (*Table 2*).

In the area of the *separation of substance,* a significant *improvement* (8 out of 10 children) was also observed in the experimental group children's *knowledge of using a strainer or sieve* for sieving compared to hand-picking (*Table 1*). Hand-picking for separation purposes was an answer for the majority of both the experimental and control groups in Test 1. As seen in Test 2, the majority of the experimental group suggests sieving as a method of separation, which they had not considered before. The results of the control group are the same as in Test 1.

Science Process Skills Development

Observations among the children of the experimental group while they were using the four IBs were collected. *Table 3* shows the results of children's degree of success and autonomy. It can be observed that the children were successful in solving the first three IBs, with an average success rate of 9 or higher on a scale of 1 to 10. The greatest success involved the *Weighing* IB, the third in a row offered to them.

It can be observed that the average level of autonomy was also high, at 2.5 or 2.6 on a scale up to 3. The last IB, *What Do You Know About A Substance?*, offered as a test of knowledge and skills arising from the first three IBs using new examples, turned out to be too challenging for most children. The average success rate for this IB was significantly lower, at only 5.3. Children were less autonomous on average, scoring only 1.9, as shown in *Table 3*.

Table 3

Overall results for the children's success and autonomy for the four IBs, the best completed and the most challenging task for each IB.

IB/autonomy and success	Nuts and Bolts	Separation of Substance	Weighing		What Do You Know About A Substance?
Average autonomy (1-3)	2.5	2.6	2.6		1.9
Average success (0-10)	9	9.2	9.4		5.3
The best-completed task	Experimentation and classification of nuts by buoyancy	Selection of a wheat-buttons mixture separation and classification process	Weighing, bigger ball is heavier, and both marbles	Comparison of weight without weighing and verification by weighing two balls of approximately the same size	Classification of wheat semolina, metal nuts and plastic buttons (magnet and sieve process reasoning, no hands)
Average autonomy (1-3)	3	3	3	3	2.6
Success (0-10)	10	10	10	10	9
The most challenging task	Ordering the bolts by size from largest to smallest	Ordering buttons by size (instruction showed the middle of the sequence)	Ordering the objects by weight using the balance scale		Separation of wooden sticks and metal nuts by inferring the use of the buoyancy and straining test
Average autonomy (1-3)	1.6	2.3	2		2.4
Success (0-10)	6	7	5		3

The results in Table 3 show that the most challenging task for the children in the *Nuts and Bolts IB* was ordering the bolts by size from largest to smallest, in which they recorded the lowest levels of both success and autonomy. The size-ordering task (*Separation of Substance IB*) also proved challenging to complete. Ordering the objects by weight using the balance scale in the *Weighing IB* was also challenging. *Table 3* shows that the children were very successful (10) and autonomous (3) when weighing pairs of objects. Difficulties only arose while putting multiple objects in order, which presented a mental challenge successfully solved by half (5) of the children.

When monitoring the development of a specific SPS, we focused on monitoring children's autonomy in the SPS of classifying, ordering, and measuring/weighing. We identified autonomy as the variable that fluctuated more than success, conditioned by the educator's support. Thus, autonomy shows progress in the child's development of a particular SPS. The related graphs are shown in Figures 6 to 8. We did not include results for the fourth *What Do You Know About A Substance?* IB in the comparison because the complexity of the tasks in new examples led to lower scores for both autonomy and success (*Table 3*).

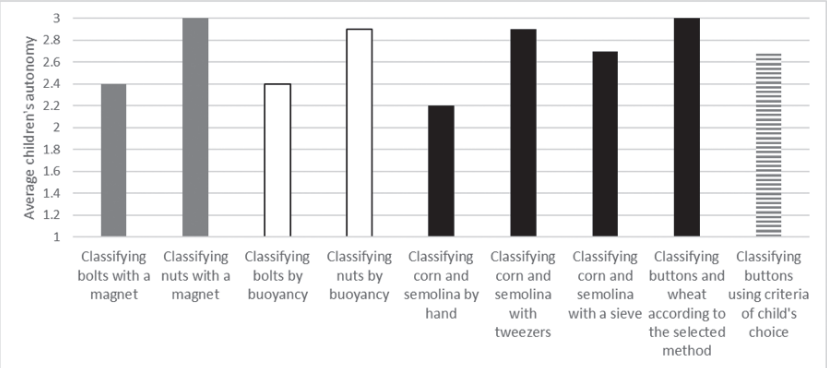
Figure 6 shows the children's average autonomy in a particular task on the instructional card that required various materials to be classified. If we observe the results for sets of tasks related to classification using a magnet (grey), based on buoyancy (white), and by the method of separation by hand-picking, with tweezers, sieving or by the method of choice (black), we see that the average autonomy within a set increases with the order in which the tasks are performed. Autonomy is lower when children first carry out a particular SPS with the chosen material. On average, it is always higher when they use the SPS within the same set of tasks.

The classification of buttons according to the child's criterion (striped) shows a high level of average autonomy, which we found surprising as it was the first time the children faced the task of choosing their classification criterion.

Surprisingly, when developing the SPS of ordering, we observe a trend of increasing child autonomy depending on the order of the first six tasks offered (grey) on the photo-type instructions for inquiry within the three IBs, as shown in Figure 7. The value 2.3 which is an outlier and is related to the instruction card with more symbols where only the middle sequence is shown.

Figure 6

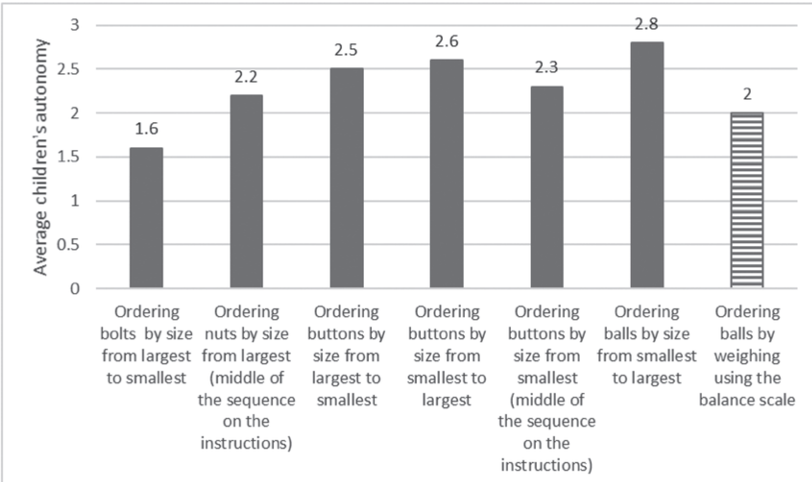
Development of the SPS of classifying shown as an average children's autonomy score on the sequential classifying tasks in the Nuts and Bolts (grey and white) and Separation of Substance (black and striped) IBs



Legend of autonomy score: 3 – autonomous child, 2 – non-verbal help from educator is needed, 1 – verbal help from educator is needed.

Figure 7

Development of the SPS of ordering shown as an average assessment of children's autonomy in the sequential ordering tasks in the Nuts and Bolts, Separation of Substances, and Weighing IB.



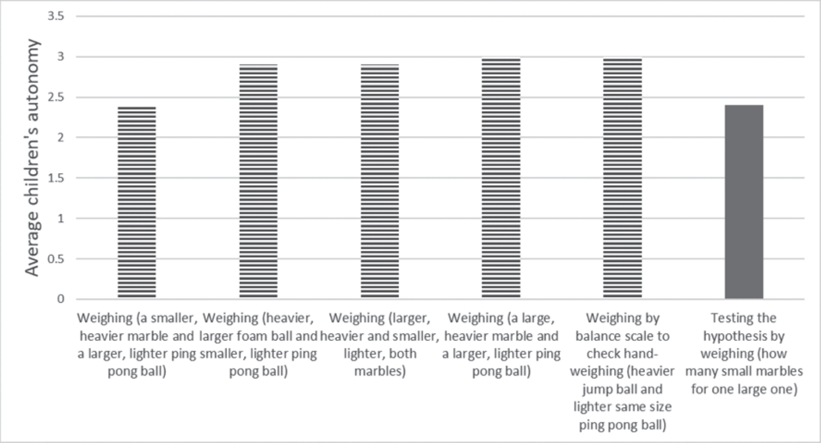
Legend of autonomy score: 3 – autonomous child, 2 – non-verbal help from educator is needed, 1 – verbal help from educator is needed.

The task of ordering the balls by weight, using a balance scale for weighing (the striped bar in Figure 7), was not completed by five children (half) who needed verbal help. Nevertheless, half (5) of the children completed the task successfully and with a high degree of autonomy.

Figure 8 shows the average autonomy of the children when inquiring into the weight measurement of the six tasks with the Weighing IB. Once again, the lowest autonomy (2.4) is observed for the first task, in which children first encounter autonomous handling of the balance scale. Despite the unexpected outcome, and with some non-verbal help from the educator, they all successfully identified the smaller ball as heavier since it ended up lower than the equilibrium position of the scale.

Figure 8

Development of the SPS of measuring shown as an average assessment of children's autonomy in the sequential weighing tasks in the Weighing IB.



Legend of autonomy score: 3 – autonomous child, 2 – non-verbal help from educator is needed, 1 – verbal help from educator is needed.

All children were also successful and autonomous while weighing two balls of the same size (a super ball and a ping pong ball) with the balance scale. In the last task (grey in Figure 8), they tried out weight measurement with a non-standard unit, and autonomy dropped to 2.4 as three children (out of 10) needed verbal help.

Discussion

Progress with content knowledge

The results of this study demonstrate a notable enhancement in content knowledge development for the experimental group that engaged with the IBs. Specifically, in the realm of magnetism, we can infer that children in the experimental group are more likely to progress towards the objective of generalising that metal objects are attracted by magnets, while wooden and plastic objects are not. Additionally, it is evident that the children in the control group in the study did not encounter any new experiences with magnets outside the kindergarten environment.

Based on the findings, we can confidently assert that the use of the Inquiry Boxes (*Nuts and Bolts* and *What Do You Know About A Substance?*) contributed to the improvement of content knowledge about magnetism and buoyancy among the children in the experimental group. Furthermore, the children exhibited significant progress in accurately classifying objects according to their buoyancy, referencing the material as the determining factor rather than the object's mass or weight.

These results align with prior research by Hsin and Wu (2011) and Smithenry and Kim (2010), who found that pre-schoolers could generalise an object's buoyancy based on its material composition. The acquired knowledge through interaction with the IBs, such as the understanding that metal nuts and bolts sink while plastic and wooden ones float, had a positive impact on their subsequent application of the concept of density in further schooling. Previous research studies (Clements & Sarama, 2016; Saçkes, 2013) have highlighted the significance of early childhood education and skills as predictors of children's science achievement in later grades.

Similarly, the experimental group's exploration of weighing using the carefully prepared IB materials demonstrated a clear understanding of the concept of weight through practical examples, corroborating findings by Bar et al. (2016) in a study on introducing the concept of weight. Handling the strainers and sieves while exploring the prepared substances and mixtures with different particle sizes and engaging in tasks from the *Separation of Substance* and *What Do You Know About A Substance?* IB contributed to an improved understanding of separation techniques in this area, a finding also supported by Abdo (2022).

The deliberate preparation and selection of customised mixtures and sieves, as Bajd et al. (2013) also suggested, further enhanced the daily experience of sieving. The implementation of the prepared IBs facilitated purposeful reflection on the comparison of various separation techniques.

Overall, the experimental group of four- to five-year-old children exhibited significant progress in their content knowledge across challenging science areas, including magnetism, buoyancy, weighing, and separating of substances. This progress can be attributed to their exploration of materials and tools through the photo-type instructions provided in the IBs, which allowed them to learn and practice scientific process skills (SPS). The introduction of thematic IBs in children's play has the potential to foster knowledge progression in other areas of early science education.

Science Process Skills Development

On average, children consistently demonstrated a higher level of autonomy when using SPS within the same set of tasks, including sorting, classifying, and measuring/weighing. Similar observations were made by Jirout and Zimmerman (2015) and Larimore (2020), emphasising the significance of content knowledge in SPS development. Our research also highlighted the importance of context in thematic sets, which aligns with the findings of the SPS development in classifying.

The diverse collection of materials, such as buttons, allowed children to choose various criteria for classifying, like colour, size, and the number of holes. Devjak et al. (2021) identified this autonomy in selecting criteria as essential.

Understanding instructions featuring more symbols proved more challenging for 4- to 5-year-olds, even though none of the instructions provided the entire solution, only a partial part. When comparing the average autonomy value (2.2) for a similar ordering problem with nuts and buttons (Figure 7), where the middle of the sequence was shown on the instruction card, we observed a slight increase in average autonomy value (2.3) for the second task using a different material. This suggests adequate development of ordering SPS and the ability to transfer knowledge to new situations and contexts, which is essential in (ECE) as noted by Dilek (2020).

Ordering by weight without considering the volume (size) of objects was particularly challenging for some children, even at higher grade levels (Bar et al., 2016). However, the results indicated that the materials in the IBs were suitable for developing ordering SPS in various contexts.

Children used the stated principle of weight measurement more meaningfully and autonomously after successfully completing the first task of weighing pairs of balls (Figure 8). This finding aligns with those of Bar et al. (2016) in their comparative analysis.

Identifying the equality of masses with a non-standard unit shown by the balance scale posed a new challenge for the children, resulting in decreased autonomy. Similar to classifying, the development of weight measurement SPS showed progress in autonomy when the process was familiar and comparable. Children learned to measure the weight of objects independently, irrespective of their size and material.

Through inquiry with the *Weighing* IB into the weight properties of concrete materials, children acquired a technique applicable in everyday life to identify and compare the weights of diverse objects, consistent with Preston and Love's (2021) findings with preschool children. However, when faced with a new task involving weight equality, some children (5) required explanations. Detailed observations indicated that these children also needed assistance with the first task and might have developed greater autonomy through repeated exploration of the same IB, which is in line with predictions from undergraduate research on IBs in early childhood education (Kopič, 2021; Lamovšek, 2015; Smiljan, 2021).

In conclusion, the results suggest that children develop autonomy in SPS of classifying, ordering, and measuring when they engage in inquiry using several different IBs in sequence.

Conclusions

When considering the study as a whole, science inquiry with the IBs was shown to yield effective results regarding the SPS development and content knowledge of four- to five-year-old children. By engaging in tasks that utilise the Inquiry Boxes (IBs), a child not only acquires knowledge about the specific materials or collections within an IB but also gains transferable skills and develops scientific process skills (SPS) relevant to the discovery of content knowledge and early childhood education (ECE). These skills and knowledge prove to be crucial for the child's future development during their school years when the knowledge and skills acquired are further honed and demonstrated in scientific achievements, as highlighted by Larimore (2020). For pre-schoolers, inquiry through IBs arouses curiosity and a desire to explore new things. Guided tasks on photo-type instructional cards allow for a sufficient degree of autonomy and achievement. The presented form of individually guided inquiry for children using thematic IBs is recommended as a proven teaching aid for developing children's SPS and knowledge for the separation of substances, weighing and magnetism. The results of the study were obtained from a small sample and cannot be generalised to the whole population, which may be seen as a limitation and as offering the potential for further research within ECE.

We also note that it is often too simplistic to categorise specific SPS as basic and simple SPS, as classified by McComas (2014) and Saçkes (2013). Indeed, we found that the choice of materials already influences the task's difficulty, as well as the success and autonomy in solving the task. This was seen in the ordering by size for collections of materials made up of individual particles rather than in one piece.

Inclusion of the *What Do You Know About A Substance?* IB as a testing material for both groups of children presented a challenge since it covered the content knowledge and SPS developed in the other three IBs used in the research. Despite the experimental group's lower success and autonomy scores due to more challenging tasks, we anticipate a difference in the success and autonomy of the experimental group compared to the control group. This additional test would help fill a gap in our research, providing further confirmation of the significance of children's learning through inquiry-based methods, particularly regarding the transfer of knowledge and skills to new examples and problem-solving situations (Klahr & Chen, 2011).

Therefore, educators should introduce inquiry-based activities in which children use developmentally appropriate materials to undertake observations, classifications, ordering, measurements, predictions, experimentations and other SPS to facilitate SPS development in different contexts and content knowledge.

To increase educators' awareness, one of the main elements of ECE applications, additional IBs for different content knowledge, could be developed and their effectiveness investigated. For some of these, it would be worth looking for IB designs in existing undergraduate final theses (e.g., Brbre, 2012; Flego, 2015; Kopič, 2021; Kvas, 2019; Lamovšek, 2015; Perko, 2008; Smiljan, 2021; Šenica, 2022; Ungar, 2020) as these also show great potential for developing children's autonomy. For children, the IB are an opportunity to experience, perhaps for the first time, fully autonomous science inquiry, which simultaneously offers a unique and stimulating learning environment.

Disclosure statement

The authors have no conflict of interest to declare.

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Appendix: The Inquiry Box Tasks

INQUIRY BOX	TASKS AS SHOWN BY THE PHOTO-TYPE INSTRUCTIONAL CARD
Nuts and Bolds	Ordering the bolts by size from largest to smallest Ordering the nuts by size from largest (instruction shows the middle of the sequence) Fitting nuts to bolts Experimentation and classification of bolts by magnet Experimentation and classification of nuts by magnet Experimentation and classification of bolts by buoyancy Experimentation and classification of nuts by buoyancy Predicting: Are all plastic bolts and nuts magnetic?
Separation of Substances	Classifying corn and semolina by hand Classifying corn and semolina with tweezers Classifying corn and semolina with a sieve Selection of a wheat-buttons mixture separation and classification process Ordering buttons by size from largest to smallest Ordering buttons by size from smallest to largest Ordering buttons by size (instruction shows the middle of the sequence) Classifying buttons using criteria of child's choice and communicating
Weighing	Ordering balls by size from smallest to largest Weighing (a smaller, heavier marble and a larger, lighter ping pong ball) Weighing (heavier, larger foam ball and smaller, lighter ping pong ball) Weighing (larger is heavier, both marbles) Weighing (a large, heavier marble and a larger, lighter ping pong ball) Comparison of weight without weighing and verification by weighing two balls of approximately the same size Ordering balls by weighing using the balance scale Predicting: How many smaller marbles does one bigger one weigh? Testing the hypothesis by weighing (How many smaller marbles does one bigger one weigh?)
What Do You Know About A Substance?	Classification of wheat semolina, metal nuts, and plastic buttons (magnet and sieve process reasoning, no hands) Separation of wooden sticks and metal nuts by inferring the use of the buoyancy and straining test Ordering equally-sized packages of substances by particle size Ordering equally-sized packages of substances by weighing Classifying equally-sized packages of substances using criteria of child's choice and communicating

Biographical note

Nika Golob, PhD, is an assistant professor in the field of didactics of early science at the Department of Preschool Education at the Faculty of Education at University of Maribor. Her research interests include early learning and teaching of natural sciences, scientific iquiry in early years, science literacy, environmental education and as well preschool teacher education.

Vanja Ungar is a preschool teacher in the kindergarten Blaže in Nežica in Slovenska Bistrica, Slovenia. Aware that inquiry-based learning approach in science has an important effect on children holistic development, she has prepared a diploma thesis in this field. As a preschool teacher, she regularly integrates inquiry-based learning and the use of science-interesting materials and phenomena from everyday life into children's science activities.