Promoting third grade pupils’ learning of science knowledge through project-based learning in a Finnish primary school

Abstract
We explored third grade pupils’ (9–10-years, n = 22) learning of various science knowledge while engaged in scientific practices during a designed project-based learning (PBL) module. The topics selected were familiar to pupils, such as the dissolution of sugar and rising of dough with yeast. The study sheds light on the type of knowledge the pupils communicate with while they are involved in scientific practices and creation of digital artefacts. The video recorded data were collected in a Finnish primary school classroom. In total 22 clips (duration of 2–8 minutes) were the primary data. The qualitative content analysis
revealed that the pupils engaged in factual, conceptual, procedural, and metacognitive knowledge in PBL collaborative activities. The analyses described pupils’ interactions and actions when they employed these different types of knowledge. In conclusion, PBL modules based on familiar everyday contexts can support primary pupils to learn scientific practices and use versatile types of knowledge.

INTRODUCTION
There is scarcity in educational research that focuses on how to support primary-aged pupils’ (9–10-years) learning of science competencies needed in adulthood, such as recognizing and posing questions or problems and finding answers to them (Krajcik & Czerniak, 2018; Krajcik, Miller, & Schneider, 2021). Project-based learning (PBL) has been recognized as supporting (lower-secondary school) pupils in the learning of science core ideas and knowledge by engaging the pupils collaboratively in scientific practices and the construction of artefacts (Krajcik et al., 2018). The science core ideas are explanatory (i.e., used for explaining phenomena), generative (i.e., used for investigating and solving problems) and relevant (in the personal, local and global contexts) and needed in scientific reasoning, problem solving and critical thinking in the context of everyday life (Krajcik et al., 2021). In this research context core ideas were: all materials and chemical properties that are used for identifying them; a chemical reaction is a process in which substances interact with each other to create a new substance with its own properties. In more detail the pupils learnt how substances like yeast, sugar and water reacted to generate new substances. Pupils also learnt how this phenomenon can be employed in baking. However, there is a need to study more thoroughly how these essential acts of “doing science” are perceived and demonstrated in young, primary-aged pupils’ classroom interactions and actions.

According to Lavonen, Loukomies, Vartiainen and Palojoki (2022), young pupils engage in scientific practices while making sense of everyday life phenomena through PBL. While engaging in scientific practices, children build and use different kinds of knowledge. Still, very little is known about what kind of knowledge they build and how different types of knowledge manifest in pupils’ communications and activities during PBL. Here, communication in classroom interactions is regarded as a multimodal practice where all available semiotic resources serve making and sharing meanings (Taylor, 2014). Hence, the knowledge that pupils employ manifests itself in their actions and use of tools, in addition to vocalization. This idea derives from pragmatists, who emphasise the acquisition and use of knowledge within the concept of action in a physical and social environment (Biesta & Burbules, 2003; Dewey, 1938).

To fill the gap in the research, this study aims to shed light on the type of knowledge (factual, conceptual, procedural and metacognitive knowledge), how pupils communicate with when they make sense of everyday life phenomena by engaging in scientific practices and creation of digital artefacts, and how knowledge manifests in their speech and communication practices in the classroom. Little is known about how primary-aged pupils use conceptual and procedural knowledge in scientific practices. The following research question guides the study: In what ways are different types of knowledge manifested in pupils’ interactions and actions in their collaboration during PBL in a small group (4–5 pupils)?

PROJECT-BASED LEARNING AS A PEDAGOGICAL APPROACH
Project-based learning (PBL) is a pedagogical approach, which has its origins in Dewey’s (1938) and Kilpatrick’s (1918) work, which guides pupils to collaborate and engage in scientific practices to help them make sense of the everyday life phenomena. The key ideas of PBL involve pupils in collaborative learning and PBL starts with a driving question, that is, an everyday life problem to be solved, which contextualizes learning, connects new ideas to previous ideas and guides the learning process (Krajcik et al., 2018). Pupils explore the driving question by participating in scientific practices which are similar to those of professional scientists, such as asking a scientific question, observing, classifying,
predicting, measuring, interpreting, and analysing data; developing and using models to represent phenomena, objects and processes; and developing explanations and proposing solutions supported by data and models (Krajcik et al., 2018).

There are three practical phases in PBL: first, the pupils become familiar with the driving question and phenomena (Lederman, Lederman, & Antink, 2013). When addressing the driving question, pupils can use digital technology together to create a set of tangible artefacts (Erstad, 2002), which they can share with each other and potentially use to direct their learning and knowledge building (Chin & Osborne, 2008). Second, the pupils collect and analyse data and construct a model, which describes the phenomena according to the aim. Third, they reflect on their learning and group work.

PBL has been selected as the pedagogical approach of this study because it integrates the learning of disciplinary science core ideas and scientific practices while pupils collaboratively work and use knowledge according to a driving question.

**PBL drives pupils to learn different types of knowledge**

Crawford (2014) and Hodson (2014) argue that young pupils can plan and carry out meaningful observations and investigations as a way to learn different types of knowledge. Krathwohl (2002) categorizes the knowledge to be learned as factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge.

Table 1. Four types of knowledge with examples from the context of this study (adapted from Krathwohl, 2002).

<table>
<thead>
<tr>
<th>Factual knowledge</th>
<th>Conceptual knowledge</th>
<th>Procedural knowledge</th>
<th>Metacognitive knowledge</th>
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<tbody>
<tr>
<td>The facts that pupils use or observe, such as terminology about tools and materials (<code>Pupil points a thermometer on the table and says that s/he will use it</code>).</td>
<td>Conceptual connections between the facts or variables that pupils use, observe, or investigate and their prior knowledge, such as classifications and categories (<code>Pupil adds hot water [high temperature] to one glass and cold water [low temperature] to another</code>).</td>
<td>Empirical knowledge that pupils learn about how to do things, such as subject-specific skills and algorithms (<code>Pupil knows to first measure the weight of the water and then the temperature</code>).</td>
<td>Knowledge about general learning strategies, such as strategic knowledge (<code>Pupil draws a picture for explaining phenomena, self-evaluation of actions, strategies and outcomes</code>).</td>
</tr>
</tbody>
</table>

- Specific details and elements (`Pupil knows how to use a spoon for mixing`).
- Principles and generalizations (`Pupil collects gas [carbon dioxide] to a balloon`).
- Theories, models and structures (`Pupil knows that mixing speeds up dissolution`).
- Subject-specific techniques and methods (`Pupil can use the kitchen scale to control the variables`).
- Criteria for determining when to use appropriate procedures (`Pupil knows that a thermometer should be kept long enough in water, while measuring the temperature`).
- Knowledge about cognitive tasks (`Pupil remembers to use technology in recording the observation`).
- Self-knowledge (`Pupil presents the project outcome to peers for getting feedback`).
Pupils’ interactions and actions play an important role when pupils use, share and co-create the four types of knowledge (Krajcik et al., 2018; Vartiainen & Kumpulainen, 2020). We are interested in the ways in which these types of knowledge are manifested in collaboration situations, such as pupil-to-pupil interaction, and action, such as observation and investigation. Consequently, the different types of knowledge could be manifested in collaboration situations through:

**Interaction**
- pupil-to-pupil interaction
- pupil-to-teacher interaction

**Actions**
- scientific practices, such as asking scientific questions, observation, measurement, predicting, developing models, using models and constructing explanations
- use of tools and
- use of technology

A clear definition of variables is an important component of investigation for enabling pupils to understand what is being investigated (Osborne, 2014). Another component is controlling variables, that is, holding all variables constant except the variable that is being manipulated (Krajcik et al., 2018). Young pupils may discuss relative scales of variables, such as hottest and coolest, without reference to particular units of measurement, for example, measurement of water temperature (Krajcik et al., 2021), and also relate observation to pre-existing knowledge and earlier experiences (Ahtee et al., 2009). Consequently, while pupils make scientific observations, they employ conceptual and procedural knowledge. Previous research (Siry, Ziegler, & Max, 2012) has proposed that young pupils can construct their conceptual knowledge in pupil-to-pupil multimodal interactions during science investigations. Pupils can enact science learning collaboratively and multi-modally (Taylor, 2014). This happens when pupils interact in science learning activities such as explaining, and representing properties through, for example, investigating water through their observations. Moreover, observations and investigations include not only how things look like but also how they feel, how they sound when tapped, how they smell, and, in cooking or baking projects, how they taste (Krajcik et al., 2021). Therefore, pupils should be asked to express their ideas and observations in various ways, for example, through drawings or oral description. In these expressions, pupils can describe the outcomes of their own observations and investigations in terms of models. Such experiences help pupils develop the concept of a model and represent their current understanding of their observations and investigations (Osborne, 2014).

*The Finnish core curriculum emphasizes the use of knowledge in everyday life situations*

Learning science research has shown that pupils cannot learn disciplinary content without engaging actively in disciplinary practices, and that they cannot learn these practices without actively constructing their understanding of the discipline’s core ideas through disciplinary practices and by linking these ideas in their everyday life contexts (Sawyer, 2014). The Finnish National Core Curriculum for Basic Education (FNCCBE, 2014) emphasizes the use of science knowledge in various situations and the engagement in scientific and engineering practices while solving problems. Home Economics (HE) provides an exemplary platform, by supporting pupils’ skills and knowledge in planning and working together, and in experimenting and explaining phenomena related to food preparation (Haapaniemi, Venäläinen, Malin, & Palojoki, 2021). Moreover, a deeper understanding of reactions and phenomena related to food preparation requires basic knowledge of Chemistry, Biology and Physics. In HE, it is important to understand how pupils connect and synthesize everyday life knowledge and practices from different disciplinary core ideas in classroom settings.
CASE STUDY METHODOLOGY

A descriptive case study (Yin, 2018) was selected as the methodological approach because our aim was to scrutinize in depth through a case how different types of knowledge were manifested in pupils' interactions and actions in their PBL in a primary school classroom. The case study can capture the complexity and holistic nature of a learning situation in a specific real context of PBL learning.

The PBL learning module design had two main goals: 1) to design a PBL module for the primary school classroom, and 2) to advance researchers’ theoretical understanding of pupils’ learning of science core ideas and scientific practices (Sandoval, 2014). The PBL module considers age-appropriate multimodal pedagogy, where contextualization of pupils’ learning is considered an important characteristic (Table 2). It is typically realized through introducing a driving question that conceptualizes and guides learning by connecting new ideas to previous ones and to everyday life situations. In this study, driving question was introduced to children through story. Storytelling is a method to contextualize the problems through narrative thinking that is natural for young children. (Vartiainen et al., 2020). We (Lavonen et al., 2022) have beneficially used storytelling earlier to contextualize the problems and to introduce the driving question.

The first story described with a pre-planned video how the rate of sugar cube dissolution in tea water could be investigated when the variable was one of mixing, water temperature, or amount of sugar. In the third lesson, the story was a poem read aloud by the teacher that introduced the principles of baking a bun and highlighted how small bubbles can be produced with sugar and yeast and warm water. In the lesson, pupils were challenged to develop a solution of sugar, water and yeast in which bubbling could be observed when there was one selected variable in the investigated and developed solutions.

PBL emerges from social interaction in group learning, which is important when pupils develop their understandings of principles and ideas through sharing, using and co-creating ideas with other group members (Krajcik et al., 2018). Therefore, the PBL module reflects a Vygotskian idea of learning through social interactions in a small group (Vygotsky, 1978). Interaction and discussions with peers support the understanding of core ideas (Krajcik et al., 2021). Pupils interact through different roles as project participants, as introduced in the first story (e.g., designer, instrument manager and technology manager). Digital technology (i.e., laptops, tablet devices and digital platform) were also integrated into pupils’ learning processes; for example, the Microsoft Teams platform has been systematically used in the classroom in every primary school year (FNCCBE, 2014).
Table 2. Summary of the aims, driving questions and artefacts created by pupils in the PBL module.

<table>
<thead>
<tr>
<th>Lessons</th>
<th>Aim</th>
<th>Driving Question</th>
<th>Artefacts created by the pupils</th>
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<tbody>
<tr>
<td>Orienting lesson</td>
<td>The project’s objectives (science investigation) and use of digital technology was introduced to the pupils.</td>
<td>Orientation to driving question through observing a video story of young people experimenting in the kitchen and recognizing the characteristics of an investigation.</td>
<td>A tangible research design with scientific tools and materials on the table.</td>
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<tr>
<td>Second lesson Asking scientific questions and investigating everyday life phenomena</td>
<td>The pupils’ asked scientific questions and designed a “tea water” investigation, i.e., the dissolution of sugar in water.</td>
<td>How do scientists make sense of the phenomena?</td>
<td>A written research report (Word document) about the investigation, which is shareable to the whole class through the O365 Teams platform.</td>
</tr>
<tr>
<td>Third lesson Asking scientific questions, planning, and investigating everyday life phenomena</td>
<td>The pupils engaged in scientific questioning and designing and implementing an investigation of the production of small bubbles (carbon dioxide) with sugar, water and yeast in the context of a baking investigation.</td>
<td>How do scientists make sense of the phenomena?</td>
<td>A tangible research design with scientific tools and materials on the table.</td>
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<td></td>
<td>→ (NB! the phenomenon (of the rising of dough due to yeast) is addressed at the macro level by the HE phenomena, not at the science level.)</td>
<td></td>
<td>A written research report (Word document) about the investigation, which is shareable to the whole class through the O365 Teams platform. Photos (tablet computer) of the pupils’ work.</td>
</tr>
<tr>
<td>Presenting the outcomes and evaluating the lesson</td>
<td>During this final lesson, the teacher directed the reflective discussion regarding small group learning processes.</td>
<td></td>
<td>Every group presented their projects and digital artefacts (e.g., photos) from the third lesson through the shared Teams platform.</td>
</tr>
</tbody>
</table>

Data

Participants
This case study was conducted in one Finnish primary classroom in the Helsinki metropolitan area in spring 2018. The designed learning module was implemented in the third grade, where the pupils ($n = 22$) were aged between 9 and 10 years. All pupils participated throughout the learning module, but two pupils (pupils 10 and 11) from group 4 were absent from the third lesson. Authors 1 and 2 were teachers during the PBL module, which increased knowledge about the pupils’ learning process. However, we acknowledge that the dual role might cause many issues such as biased observations. These issues were openly discussed and recognized to remain objectivity. A carefully designed and prepared learning module, such as a composition of small groups (4–5 pupils), enabled teachers to give intensified scaffolds to those pupils who need it most (Figure 1).
Data Collection
The data was collected through video recordings of pupils' collaboration, communications and actions, and design of the digital artefacts (Derry et al., 2010). The data consisted of video recordings of four lessons, each lasting 90 minutes, in which each of the five groups of pupils was captured by one video camera and observational field notes of the learning module were taken (Figure 1).

Teacher (T1) was a visitor teacher who was responsible for teaching during the module. The pupils' own teacher acted more as the observer (T2). The teacher observed the pupils' readiness to participate in the study. Prior to implementation of the study, permissions were acquired from each of the pupils' guardians and from the school administration. It was explained that the learning module already formed part of the annual curriculum for the third class. The pupils interacted with the researchers and were aware that they could at any moment tell their teacher to stop the video recording.

Video data analysis process
Video data were analysed by using qualitative content analysis (Earl Rinehart, 2021). The analysis proceeded in multiple ways, such as systematic focusing and sequential processes of verbal and non-verbal interactional phenomena (see Figure 2), (Goodwin, 2000).
RESULTS

Following the case study methodology, we present four different excerpts that demonstrate how different types of knowledge are manifested in pupils’ interactions and actions in their collaboration in a small group (Figure 3). The excerpts are chosen to cover the different lesson phases. The learning processes of different groups of pupils are represented where possible in order to illustrate the variation in pupils’ collaboration.

Figure 3. A still photo (Group 1) from the video data on how pupils build different types of knowledge in PBL through activities such as creating a set of tangible digital artefacts.

Conceptual knowledge develops through teachers’ scaffolding

The first excerpt shows how the teacher guides the pupils to the use of scientific concepts and procedural knowledge and by doing so, encourages them to ask well-formulated scientific questions that they can approach empirically and investigate. It is important that primary-aged pupils are able to design investigations and control experiments and simple dependent variables (Krajcik et al., 2018). This excerpt emphasises pupils’ significant efforts to develop their metacognitive knowledge as they direct their own learning. They demand a successful scientific question from themselves by designing the question in multiple ways in their actions and interactions while conducting the investigation collaboratively. The pupils needed strong pedagogical scaffolding by the teacher when formulating a scientific question during the first phase of PBL. The episode also describes how question-posing can pique curiosity, as well as arouse interest in the topic or phenomena under study. Therefore, it is important that the teacher asks guiding questions, which can lead to the construction of conceptual knowledge in this first phase of the inquiry process.
Group 5
28.26 minutes at the beginning of lesson 3, (8.07 minutes),
Aim: The production of small bubbles (carbon dioxide) with sugar, water and yeast in the context of baking investigations
Actions: pupils sit in their own seats at their table group, and they begin to design their own scientific questions through a collaborative learning activity.

Pupil 20: “What is the rationale for our group work, and what is the rationale for doing it this way?”
Pupil 22: “What is our (group’s) scientific question of investigation of baker’s yeast?”

Procedural knowledge (Subject-specific skills and algorithms):
Pupil (20) actively designs systematic investigation as the pupil seeks to build the scientific question from one variable.

Metacognitive knowledge (Knowledge about general learning strategies):
Pupil 20 and Pupil 22 refer in their speech, “to our group,” and guide learning together. This is their knowledge about cognitive tasks.

Interaction (pupil, pupil):
Pupil 20 and pupil 22 wonder about how to formulate an answerable scientific question in the beginning of the lesson.

Pupil 20: “Teacher! what is the rationale for doing it this way? In the last week’s lesson, the rationale (research design) was that there were two glasses in use (--) two balloons!”

Conceptual knowledge (principles and generalisations):
Pupil 20 focus on the collection of gas in balloons.

Interaction (pupil, teacher):
Pupil 20 asks the teacher’s scaffolding about his idea of formulating scientific questions.

Action (scientific practices, planning):
Pupil 20 planning the investigation.

Action (Use of tools):
Pupil 20 references using measurements in the planning.

Teacher 1: “You are designing to conduct your investigation to be inside the balloons. It is a wonderful idea! Tell me, what ingredients are you going to put in there (in two balloons)?”

Interaction (pupil, teacher):
Teacher scaffolding to pupils by asking guiding question to pupils.

Pupil 21: “Sure! And then we’re going to put (--).” [shows to others non-verbal interaction about how to put some ingredients inside two different balloons].

Procedural knowledge (Subject-specific skills and algorithms):
Pupil 21 designs how to do things and in what order to do them.

Interaction (pupil, teacher):
Pupil 21 informs the teacher and other pupils about the order of the investigation.

Action (scientific practices, control of variables): Pupil 21 plans regarding the use of two balloons in their investigation.

Table 3. Conceptual knowledge develops through teachers’ scaffolding.
**Pupils’ use of factual, conceptual, procedural, and metacognitive knowledge while planning investigations**

The second excerpt shows that pupils use various knowledge while planning investigations, including recognition of controlled variables and dependent variables (see Figure 3). This was revealed while pupils prepared measurements, such as controlling the mass of sugar and yeast. To compare the reaction time, pupils decided to start the activities at the same time. This was decided when the pupils negotiated their roles in making the controlled investigation.

<table>
<thead>
<tr>
<th>Teacher 1: “Sugar? You mean?” [Teacher pointing to the sugar bag]</th>
<th>Procedural knowledge (Subject-specific skills and algorithms): Pupil 21 designs how to do things and in what order to do them.</th>
<th>Interaction (pupil, teacher): Teacher scaffolding to pupils by linking concepts to tools and materials as pupils pose their scientific questions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pupil 21: “I think it could be sugar, and then it will be put in baking yeast, too.”</td>
<td>Conceptual knowledge (principles and generalisations): Pupil 22 reminds others about the collection of gas in two balloons.</td>
<td>Action (Use of tools): Pupil 22 pointing to the tools and materials.</td>
</tr>
<tr>
<td>Pupil 22: “But didn’t we have those balloons too?” [Pupil pointing to balloons on the table]</td>
<td>Procedural knowledge: (Subject-specific skills and algorithms): Pupil 20 formulates and identifies an empirically answerable scientific question.</td>
<td>Interaction (pupil, teacher): Pupil 20 pose a well-formulated scientific question to others when being helped and guided by the teacher.</td>
</tr>
<tr>
<td>Teacher 2: “Yeah, you will, but what is your scientific question? I mean, you have had the idea of putting in the same amount of water (--).” Pupil 20: “Yes.” Teacher 2: “—and the same amount of yeast and temperature water.” Pupil 20: “Yes, but we will put different amounts of sugar in the balloons.” Teacher 2: “Now you should formulate a scientific question of this research design, which you’ve described.” Pupil 21: “What happens if (--) what’s the difference of (--)?” Teacher 2: “Or (--) How does sugar (--).” Pupil 20: “How does the amount of sugar affect the dissolution of yeast.” Teacher 2: “Or in this case, not dissolution or (--).” Pupil 20: “Principle of how yeast works (--) rather (--).” Teacher 2: “Yeah, that’s a good scientific question. Please write it down on your computer there!”</td>
<td>Metacognitive knowledge: (Knowledge about cognitive tasks): Pupil 22 uses technology in recording the scientific question.</td>
<td>Action (Use of technology): Pupil 22 uses a laptop to write down the scientific question.</td>
</tr>
</tbody>
</table>

[Pupil 22 is writing down the groups’ scientific question by using a laptop on the group's Teams platform for a report.]
Use of knowledge type in collaboration

Knowledge type manifested in collaboration through interaction or action

<table>
<thead>
<tr>
<th>Excerpt 2</th>
<th>Use of knowledge type in collaboration</th>
<th>Knowledge type manifested in collaboration through interaction or action</th>
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</thead>
</table>
| Group 1: 44.05 minutes at the beginning of lesson 2, (2.13 minutes)  
Aim: The production of small bubbles (carbon dioxide) with sugar, water and yeast in the context of baking investigations | Pupil 2: “Hey, remember that we need one teaspoon measurement of sugar.”  
Procedural knowledge (Subject-specific techniques and methods):  
A pupil (2) is measuring the volume with a measuring instrument; teaspoon measure. | Interaction (pupil, pupil): Pupil 2 tells others that in their investigation they will need one teaspoon measurement of sugar. |
| Pupil 1: “Hey Pupil 5, take a picture of this balloon [while waving the balloon].”  
[Pupil 5 (technology manager) takes the photo with the tablet computer.] | Metacognitive Knowledge:  
Pupil 1 remembering to use a tablet computer when recording the observation by photographing tools and materials. | Interaction (pupil, pupil): Pupil 1 is concerned whether all members of the group are working.  
Action (Use of technology): Pupil 5 takes a photo of the balloons that are used in the investigation. |
| Pupil 2: “Our group may need help from a teacher 2 because we cannot get these balloons in here [pointing to the Erlenmeyer flasks].” | Metacognitive knowledge: (Knowledge about general learning strategies, such as self-evaluation of actions, strategies and outcomes):  
Pupil 2 discusses and self-evaluates whether the group needs the help of a teacher in their investigation. | Interaction (pupil, pupil): Pupil 2 discuss with others how the group would solve the problem.  
Action (Use of tools): Pupil 2 designs a solution to keep the balloons at the mouth of the flasks. |
| Pupil 2: “Oh there’s already a teaspoon in here!” [noticing a teaspoon in the sugar bag] “Which of you wants to pour.”  
[pointing to Pupil 1 and Pupil 3]?”  
[Pupil 1 takes the teaspoon from the bag and starts measuring.]  
Pupil 3: “I do!”  
Pupil 2: “You can pour into flask number one, and you can pour into flask number two. But remember, be careful: it’s one teaspoon.” | Factual knowledge: (The facts that pupils use or observe, such as terminology about tools and materials):  
Pupil 2 notices that a measure teaspoon is in the sugar bag.  
Conceptual knowledge (Conceptual connections between the facts or variables):  
Pupil 2 reminds pupils 3 and 1 that the amount of sugar for controlling the variable is only one teaspoon measurement. | Interaction (pupil, pupil): Pupil 2 asks pupils 1 and 3 who wants to measure first and reminds pupils 3 and 1 that they want to get the measurement right. |
| [Pupil 1 scoops the sugar into the spoon and shakes it so that the extra sugar falls back into the bag]  
Pupil 2: “That seems okay.”  
[Pupil 3 observes the measurement and follows the same procedure as the second spoon.]  
Pupil 2: “But not yet” [implying that the measured sugar shouldn’t be poured into the flasks yet]. | Procedural knowledge (Subject-specific techniques and methods):  
Pupil 1 knows how to measure a whole spoonful of sugar. Pupil 1 knows that she should add enough sugar for the sugar to heap over the top of the measuring teaspoon by lightly scooping the ingredients into the teaspoon and then shaking any surplus sugar back into the sugar bag. | Action (Scientific practices, planning and measuring): Pupil 2 tells others that the measured sugar is needed later.  
Action (Using tools): Pupil 1 uses the measuring spoon to measure.  
Interaction (pupil, pupil): Pupil 2 gives feedback to others. |
### Procedural knowledge strives to build conceptual knowledge when developing a model for concept of temperature

In the third excerpt, the pupils discuss temperature and base the concept on the sensory experience of warmth (see also Mäntylä & Koponen, 2007). This is the simplest model for the concept of temperature, and it is supported by the pupil’s prior knowledge and experiences from everyday life. In the classroom episode below, sensory experiences support pupils in developing an understanding of scientific concepts and processes. Moreover, they connect the measurement of temperature to their sensory experiences.
**Table 5. Procedural knowledge strives to build conceptual knowledge when developing a model for concept of temperature.**

<table>
<thead>
<tr>
<th>Excerpt 3</th>
<th>Use of knowledge type in collaboration</th>
<th>Knowledge type manifested in collaboration through interaction or action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>46.68 minutes at the beginning of lesson 2, (2.08 minutes)</td>
<td></td>
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<tr>
<td>Aim: Dissolution of sugar in water</td>
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<tr>
<td>Actions: pupils practice measuring water temperature with a thermometer for the first time. According to the scientific question formulated by themselves, they want to know how the temperature of the water affects the rate of dissolution of the sugar in water.</td>
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</tr>
<tr>
<td>Pupil 3: “So do we have to measure this (water temperature, in the beaker) [takes the thermometer in hand]?”</td>
<td>Metacognitive knowledge (Knowledge about cognitive tasks): Pupil 3 guides the group to starting the investigation.</td>
<td>Interaction (pupil, pupil): Pupil 3 asks others to participate in the measurement.</td>
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<td></td>
<td>Procedural knowledge (Subject-specific techniques and methods): Pupil 3 knows that a thermometer is needed to measure the water temperature.</td>
<td>Action (use of tools): Pupil 3 takes the thermometer in his hand, and he knows thermometer is needed to measure the water temperature.</td>
</tr>
<tr>
<td>Pupil 2: “So, is this hot or cold [Touches the beaker to sense the water from the tap]?” Pupil 3: “It’s cold. [Pupil 3 brought water. You (Pupil 1) can put the thermometer there.”</td>
<td>Conceptual knowledge (Classification and categories): Pupils 2, 1 and 3 discuss water temperature and relate the concept of temperature to their sensory experience and the measurement of the thermometer.</td>
<td>Action (scientific practices, observation): Pupil 2 touches water and feels the sensory experience.</td>
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<tr>
<td>[Pupil 1 places the thermometer carefully into the beaker, leaving the scale in the correct direction. Pupils 1, 2 and 3 gather in to read the scale.]</td>
<td>Procedural knowledge (Subject-specific techniques and methods): Pupil 1 uses a thermometer to measure.</td>
<td>Interaction (pupil, pupil): Pupil 2 guides pupil 3 in measuring the temperature.</td>
</tr>
<tr>
<td>Pupil 3: “Measure it.” Pupil 2: “It’s only 20 degrees [after the thermometer has been in the water for a couple of seconds].”</td>
<td>Procedural knowledge (Subject-specific techniques and methods): Pupil 3 guides pupil 2 to measure temperature. Pupil 2 knows about the criteria for determining temperature because he knows that a thermometer should be deep enough in the water when measuring the temperature.</td>
<td>Interaction (pupil, pupil): Pupil 3 guides pupil 2 to measure temperature. Pupil 2 interprets the measurement result aloud and compares the last measuring result.</td>
</tr>
<tr>
<td></td>
<td>Action (scientific practices, carrying out an investigation): Pupil 1 measures the temperature. Pupils 2 and 3 look at the thermometer. Pupil 2 read the temperature.</td>
<td>Action (scientific practices, carrying out an investigation): Pupil 2 measures the water temperature.</td>
</tr>
<tr>
<td></td>
<td>Action (use of tool): Pupil 2 measures the temperature by using a thermometer.</td>
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</table>
Metacognitive knowledge monitors pupils’ learning progress to construct explanations about the phenomena

Pupils use metacognitive knowledge to monitor their learning progress, such as on reporting or creating artefacts by using digital technology. At the beginning of the fourth excerpt, the pupil (10) demonstrates knowledge of different learning strategies for developing explanations about dissolution phenomena. Pupil memorizes the definition of concepts as explanations and uses both factual and conceptual knowledge by combining these knowledge types in his interaction with others. Moreover, pupils’ metacognitive knowledge is connected with the driving question (see Table 2). In the following, pupils’ interaction and action is related to development of their explanations about sugar dissolution in water. The pupils are here engaged in scientific practices such as observing, classifying, analysing and interpreting their collected data. They also engage in argumentation based on their evidence and finally construct an explanation of dissolution phenomena.
Table 6. Metacognitive knowledge monitors pupils’ learning progress to construct explanations about the phenomena.

<table>
<thead>
<tr>
<th>Group 3</th>
<th>Use of knowledge type in collaboration</th>
<th>Knowledge type manifested in collaboration through interaction or action</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.22 minutes at the beginning of lesson 2, (2.10 minutes)</td>
<td>Aim: Dissolution of sugar in water</td>
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<tr>
<td>Pupil 10: &quot;That other glass looks like it's watery porridge. The other looks like just water.&quot; [waves the bottles alternately and looks at the bottles from different angles, such as the bottom.]</td>
<td>Factual knowledge (The facts that pupils use and observe): Pupil 10 uses everyday life concepts watery porridge when observing.</td>
<td>Action (scientific practices, observation, classification): Pupil 10 uses sense of sight to make observations and classifications.</td>
</tr>
<tr>
<td>Pupil 10: &quot;Why does this second one (glass with more sugar) look like that (sugar) doesn't dissolve?&quot;</td>
<td>Conceptual knowledge (Classification and categories): Pupil 10 uses concept water when classifying observable objects.</td>
<td>Interaction (pupil, pupil): Pupil 10 poses a question to drive group learning to develop explanation.</td>
</tr>
<tr>
<td>Pupil 12: &quot;Yes it will still dissolve [points at a glass with more sugar].&quot; Pupil 10: &quot;I can't observe that. This waving of the glass in my hand helps it to dissolve it (sugar) a little, and I can still do so. [Shakes the dish by waving it against the surface of the table].&quot;</td>
<td>Procedural knowledge (Subject-specific skill): Pupil 10 presents his observation.</td>
<td>Interaction (pupil, pupil): Pupil 12 tells others about observations.</td>
</tr>
<tr>
<td></td>
<td>Factual knowledge (Specific details and elements): Pupil 10 knows that waving of the glass is a good way to mix sugar and water, and that the spoon isn’t needed.</td>
<td>Action (scientific practice, investigation): Pupil 10 guides pupil 12 to debate the dissolving.</td>
</tr>
<tr>
<td></td>
<td>Conceptual knowledge (Theories, models, and structures): Pupil 10 knows that mixing affects sugar dissolution speed.</td>
<td></td>
</tr>
<tr>
<td>Pupil 10: [Tells observations aloud to the teacher 2 following the pupils’ investigation] “This glass doesn’t dissolve” [pointing at a glass with more sugar].”</td>
<td>Procedural knowledge (Subject-specific skill, and analysing and interpreting data): Pupil 10 tells teacher about their observations.</td>
<td>Action (scientific practice and analysing and interpreting data): Pupil 10 shares his observation to teacher.</td>
</tr>
<tr>
<td>Pupil 13: “So, should I write that observation here on (the computer)?”</td>
<td>Metacognitive knowledge (Knowledge about cognitive tasks): Pupil 13 asks the teacher for advice on how to write pupil’s (10) observations to the groups’ report.</td>
<td>Interaction (pupil, teacher): Pupil 13 asks the teacher for advice.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Action (use of technology): Pupil 13 tries to write down observations with the use of technology.</td>
</tr>
</tbody>
</table>
The present case study aimed to scrutinize in what ways different types of knowledge are manifested in primary-aged pupils’ (9–10 years) interactions and actions in their collaboration during PBL in a small group. The driving question of the module guided them to make sense of two common everyday life phenomena: the dissolution of sugar and rising of dough with yeast, which are both phenomena the pupils might encounter in their kitchen at home economics lessons. In the classroom context, the pupils engaged in collaboration with scientific practices, especially observation, classification, planning, carrying out an investigation and constructing and explanation, and creating digital artefacts.

The results revealed four views on the use and sharing of factual, conceptual, procedural and metacognitive knowledge during the investigations. Conceptual and procedural knowledge were most often used. For example, the concept of temperature was discussed by going through the classification of the temperature of objects through perceived sensory experiences of warmness. On the other hand, to be able to make such classifications, pupils needed procedural knowledge. Another example of creating, using and sharing concepts was the model of dissolution, which described the factors influencing the dissolution of sugar and yeast. Guided by the descriptive research question, our results demonstrate how the pupils used different types of knowledge in collaboration and how these types of knowledge manifested in their interaction in the classroom context. The creation, using and sharing of procedural knowledge was demonstrated, especially when the pupils engaged in scientific practices and the use of scientific tools. In addition, in the context of the investigations, the pupils were able...
to actively control variables relevant to the phenomenon at hand. Our results provide a rich insight into how pupils of this age take factual knowledge one step further to employing conceptual and procedural knowledge in their learning process during the PBL module, in both pupils’ interactions and action situations. Consequently, PBL provides pupils with opportunities to use science knowledge in various situations. It also supports their engagement in scientific practices, which is an aim emphasized in the FNCCBE (2014). While investigating and solving problems or explaining phenomena the pupils used science core ideas (conceptual knowledge and procedural knowledge), in more specific they recognised substances based on their properties and learnt how substances form new substances in a chemical reaction.

The results emphasize the social learning of pupils in a small group, and the overall importance of the sociocultural classroom environment (Vygotsky, 1978). We have shown how pupil-to-pupil interaction supports pupils’ learning of scientific practices and use of various types of knowledge in these practices. The everyday life context made pupils’ understanding of knowledge building more meaningful and embedded it more deeply into their previous experiences and conceptions (Krajcik et al., 2021; Sawyer, 2014). However, it was crucial that the pupils used metacognitive knowledge, which was acquired in their previous group work assignments while working in small groups. Moreover, they needed versatile IT skills, such as the ability to produce digital artefacts, as described earlier (Lavonen et al., 2022).

In conclusion, when pupils can take action and interact in the context of problem-solving linked to everyday life situations i.e. in the context of home economics, they can better see how the school-learned knowledge is useful also in their life outside the school. The creation, use and sharing of different types of knowledge was recognized in pupils’ actions in the classroom. This follows Dewey’s (1938) ideas of pupils acquiring and using knowledge while acting and interacting in a physical and social environment (see Crawford, 2014). We have shown here that primary-aged pupils’ learning activities can be manifested in multiple ways in their interaction and action, such as formulating scientific questions, making hypotheses, carrying out investigations, interpreting, evaluating, and collecting data, and constructing explanations. Our aim has not been to generalize, therefore, more attention is needed to understand how to scaffold primary pupils’ learning and support the development of metacognitive knowledge in different action situations in the classroom.

We acknowledge the limitations of this study. This is a qualitative case study, and the results reflect the authors’ interpretations of the situation. Therefore, the findings from this small-scale qualitative analysis are not intended to be generalizable. To rectify these limitations, we have aimed to support our study with a strong theoretical framework and the development of the PBL learning module, according to Sandoval (2014).

REFERENCES
Lavonen et al


