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# Capturing and Developing Teachers' Pedagogical Content Knowledge in Sustainable Development Using Content Representation and Video-Based Reflection

**Annika Forsler**[1] · **Pernilla Nilsson**[1] · **Susanne Walan**[2]

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**Abstract**
This study focuses on how science teachers' Pedagogical content knowledge (PCK) can be captured and developed with the support of Content representation (CoRe) in combination with video-based reflection when they plan, teach, and reflect on their teaching in sustainable development (SD). The theoretical framework is based on PCK, and the Refined consensus model (RCM) is used as a theoretical lens for conceptualising links between teaching practice and PCK development. Eleven upper-secondary school science teachers participated in the study. Data from two teachers were chosen to illustrate representative examples from the analysis. The findings indicate that the use of CoRe and video-based reflection provides opportunities for teachers to make their knowledge of practice explicit and help them begin to identify aspects within their own practice that are important for the further development of teaching SD. The use of RCM as an analytical tool also makes an important contribution to how RCM can be used to identify and capture teachers' PCK.

**Keywords** Pedagogical content knowledge (PCK) · Refined consensus model (RCM) · Content representation (CoRe) · Sustainable development (SD)

## Introduction

Researchers (e.g. Boeve-de Pauw et al., 2015) argue that maybe the most crucial concern of our era revolves around the challenge of preserving the Earth's resources while fostering prosperity and a good quality of life for an ever-expanding population. This significant endeavour is encapsulated by the notion of sustainable development (SD). SD implies a development that satisfies today's needs without risking the ability of future generations to meet their needs (World Commission on Environment and Development, 1987). Three interlinked perspectives are most commonly identified within SD.

✉ Annika Forsler
annika.forsler@hh.se

[1] School of Education, Humanities and Social Sciences, Halmstad University, Halmstad 301 18, Sweden

[2] Department of Environmental and Life Sciences, Karlstad University, Karlstad, Sweden

These are society, environment, and economy. Those three dimensions are key SD areas in international discourse. The three pillars of SD give shape and content to sustainable learning (UNESCO, 2006). School is likely an important factor in achieving SD in the world, as it has an excellent opportunity to influence the knowledge and abilities of society's future adult citizens (Boeve-de Pauw et al., 2015; Timm & Barth, 2021; UNESCO, 2012). Further, teachers have a crucial role when it comes to success in students' learning, and there is a strong connection between teachers' competence to create meaningful learning environments and student learning outcomes (Darling-Hammond, 2000; Hattie, 2009).

This study focuses on teachers' teaching in SD in upper-secondary school science education in Sweden. Research indicates that many teachers have a low self-efficacy for teaching SD (Evans et al., 2016; Murphy et al., 2020; Redman et al., 2021). Consequently, the gap to fill is to find out how teachers' teaching in SD can be supported.

The aim is to investigate how teachers, with the help of a reflection tool in combination with video-based reflection, may strengthen their ability to express and develop their knowledge of teaching SD. Research on teachers' planning and teaching in SD will help to inform the knowledge base for teaching and learning about sustainability issues and consequently might contribute to a sustainable world. To meet this purpose, the study uses the framework of Pedagogical content knowledge (PCK). PCK is described as the complex knowledge teachers develop through experience over time and concerns the teaching of a particular content in a specific way to improve students' understanding (Gess-Newsome, 2015).

Furthermore, PCK is a cornerstone of teachers' professional knowledge and expertise (Loughran et al., 2012), yet it is often described as tacit and inaccessible (Bertram & Loughran, 2011). Therefore, even though capturing, expressing, and identifying this knowledge is complex, it is essential for the development and improvement of teaching. To support teachers' professional development, Loughran et al. (2004) developed a reflective tool called Content representation (CoRe). This tool has been used in several contexts and has proven valuable for capturing, formulating, and developing teachers' PCK (Bertram & Loughran, 2011; Hume & Berry, 2013; Kind, 2009; Rollnick et al., 2008; Van Driel & Berry, 2017). Furthermore, to provide opportunities for reflection-on-action, video-based reflection has been used in several research studies (Coffey, 2014; Hawkins & Rogers, 2016; Kleinknech & Gröschner, 2016; Rich & Hannafin, 2009). Based on previous studies reporting about both CoRe and video-based reflections as useful tools to support teachers' development of PCK, in this study, the tools are combined to support teachers to express and develop their knowledge of teaching SD.

The framework of PCK has been developed in various international research contexts since Shulman (1986) introduced the concept. In 2019, an improved model was developed internationally by PCK researchers. The model is called the Refined consensus model (RCM) (Carlson et al., 2019). RCM expresses different realms of PCK, whereas this study focuses on teachers' personal PCK (pPCK), their enacted PCK (ePCK), and the knowledge exchange between them. In this paper, RCM is used as a framework for analysing science teachers' PCK when they plan, teach, and reflect on their teaching in SD. The following two research questions guided the study:

1. How can the combination of CoRe and video-based reflection stimulate teachers' pedagogical reasoning about teaching SD?
2. How is teachers' pPCK developed through the pedagogical reasoning process?

The following literature review will examine the concept of PCK and the reflective tools CoRe and video-recorded lessons. In the "Method" section, we describe the context of this study, elucidating how SD and environmental issues are expressed in the Swedish curriculum.

## Literature Review

### The Concept of PCK

Teaching is a complex cognitive skill that builds on teachers' professional knowledge. In 1986, Shulman introduced the concept of PCK, claiming that content knowledge and pedagogical knowledge are inseparable for promoting students' learning processes (Shulman, 1986, 1987). He highlighted the importance of pedagogical reasoning and how it affects the teacher's development of teaching. According to Shulman, pedagogical reasoning involves a cyclical comprehension process of transformation, instruction, evaluation, and reflection.

Since Shulman introduced the concept of PCK, many researchers have adopted and adapted the concept in different research contexts internationally. Researchers (e.g. Gess-Newsome, 2015; Magnusson et al., 1999; Park & Chen, 2012; Park & Oliver, 2008; Wongsopawiro et al., 2017) have explored how teachers' professional knowledge develops and how this development might be successfully supported.

To strengthen the uniformity around the concept of PCK, researchers worldwide have collaborated and developed a revised model called RCM (Carlson et al., 2019). The revised model was influenced by the model of Magnusson et al. (1999) and the previous 2012 Consensus Model (Gess-Newsome, 2015). Figure 1 shows the entire model of RCM with explanations to the right (Carlson et al., 2019).

The outermost layer in RCM in Fig. 1 represents the framework of teachers' professional knowledge. It includes content knowledge, pedagogical knowledge, knowledge of students, curricular knowledge, and assessment knowledge (Carlson et al., 2019). The RCM has three realms of PCK, represented as concentric circles. Knowledge exchange operates between the realms of PCK.

Closest to the outer circle is a realm of PCK where knowledge is public and held collectively, called *collective PCK* (cPCK). After the circle of cPCK comes the *learning context*. Teaching always takes place in a context that is affected by various factors. The circle after that is called *personal PCK* (pPCK), which represents the cumulative professional knowledge of an individual teacher created from reflection on teaching and learning experiences. Many processes interact in the development of pPCK, such as a teacher's formal education, teaching experiences, and professional sharing and reflection (Carlson et al., 2019). A teacher's pPCK includes both explicit and tacit knowledge and is unique for each science teacher (Carlson et al., 2019).

*Enacted PCK* (ePCK) is situated in the inner realm of the RCM and comprises three parts: plan (ePCKp), teach (ePCKt), and reflect (ePCKr), which are repeated in a circular process. When a teacher plans, carries out the teaching, and reflects (both reflection-in-action and reflection-on-action), a teacher utilises ePCK (Alonzo et al., 2019).

In the center part of the RCM, *pedagogical reasoning* is symbolised in the icon for teachers' knowledge and skills. Pedagogical reasoning implies that teachers' knowledge of students' understanding of a specific topic, in a specific context, provides the basis for

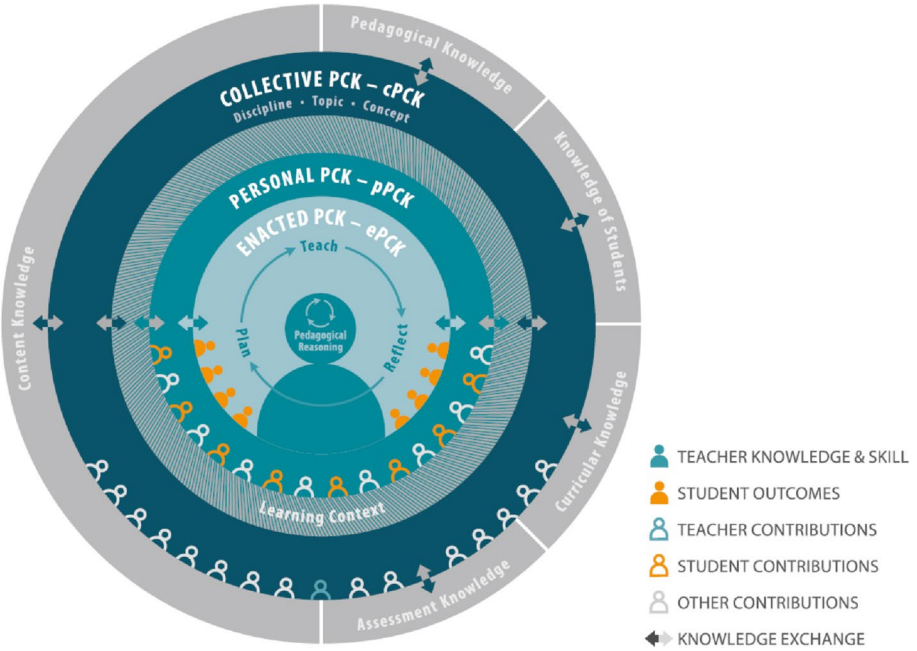


**Fig. 1** The Refined consensus model of PCK (RCM) (Carlson et al., 2019, p. 84). Used with permission

choices and actions with regard to goals, instructional strategies and ways to assess students' understanding (Henze & Barendsen, 2019).

This study focuses on the inner part of the RCM: the ePCK cycle, plan-teach-reflect, and how this cycle is influenced by the pPCK input and leads to further development of pPCK. In turn, it results in the development of teachers' ePCK, which, through pedagogical reasoning, enables a continuous refinement process of the teachers' pPCK. In Fig. 2, we illustrate the knowledge exchange process between the two realms of PCK, which lead to the development of pPCK. Figure 2 should be interpreted in a left-to right manner,

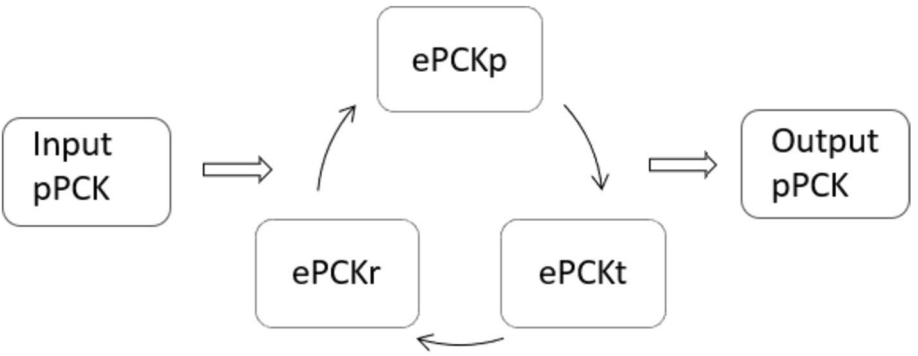


**Fig. 2** The figure shows the exchange of knowledge between pPCK and ePCK (and vice versa), the plan-teach-reflect circular pedagogical reasoning process for ePCK, and how it develops a teacher's pPCK

representing the consistent presence of teachers' input pPCK. This pPCK is enacted within the teaching activity and, through the pedagogical reasoning process within the plan-teach-reflect cycle, results in an enriched output pPCK. This iterative process continues to be repeated, fostering the development of teachers within their professional practice.

In a previous study, Behling et al. (2022a) analysed how to improve pre-service biology teachers' pPCK in the field of academic and scientific language. Based on the theory of RCM, the participants in the study were trained in the plan-teach-reflect cycle of ePCK. In a control group, the teaching of the cycle was replaced by presentations of their lesson plans. The results showed an increase in pre-service biology teachers' pPCK. The researchers recommend the use of the plan-teach-reflect cycle of ePCK to develop pPCK. Behling et al. (2022b) also analysed potential filters that moderate the transformation process between the realms of PCK defined in the RCM.

In addition, Mientus et al. (2022) reviewed previous studies to systematise existing science education research on PCK through the lens of RCM. They concluded that the results of the reviewed studies could mostly be integrated into the RCM. Moreover, they argue that the RCM can function as a meaningful theoretical lens for conceptualising links between teaching practice and PCK development. As such, this study meets that argument and presents an attempt to use RCM as a theoretical lens in analysing data on teachers' teaching in SD in upper secondary school.

### The Reflective Tool CoRe

The development of PCK is a complex phenomenon. As mentioned earlier, this knowledge is often tacit and not easily accessible, either to the teacher or to share with others. To meet the need for an articulated PCK, the reflective tool called CoRe was developed to capture and interpret PCK and to offer a concrete tool for teachers to use for their development of PCK (Loughran et al., 2004).

Research describes CoRe as successful since it clarifies and makes visible different dimensions of and connections between knowledge of content, teaching, and learning about a specific subject area in science (Bertram & Loughran, 2011; Hume & Berry, 2013; Kind, 2009; Mazibe et al., 2020; Nilsson & Loughran, 2012; Rollnick et al., 2008).

A CoRe supports and facilitates the teachers' reflections on how to teach specific subject content to promote students' learning. The design of the tool implies that science teachers articulate *Big Ideas* in a content area and respond to prompts for each Big Idea. The Big Ideas represent the central ideas and concepts within a particular science content area. Approaching the topic by identifying Big Ideas helps teachers clarify their purposes and better understand the 'essence' of what they are teaching. Big Ideas also allow teachers to build pedagogically powerful episodes for students (Mitchell et al., 2017).

The prompts cover what the students are supposed to learn about the Big Idea, why this is essential to know, and what teaching procedures should be used to teach these ideas. Eight reflective prompts are included in the CoRe to strengthen the teachers' ability to make teachers PCK explicit (Bertram & Loughran, 2011; Loughran et al., 2004).

### Video-Based Reflection to Capture, Articulate, and Develop PCK

Reflection has long been regarded as a basis for the development of PCK. Schön (1983) delved into the power of reflection for growth in professional life. He used the terms 'reflection-in-action' and 'reflection-on-action'. Reflection-in-action means reflecting on

the event while it is happening; in contrast, reflection-on-action means thinking back on an event and reflecting on how the practice can develop. Park and Oliver (2008) extended the concepts to include knowledge. They found that what the teacher does in the classroom, the enactment, is informed by 'knowledge-on-action' but also involves decision-making in the spot and therefore requires 'knowledge-in-action'. Barendsen and Henze (2019) expressed the concepts as 'manifestation of PCK-in-action' and 'articulated PCK-on-action' and stated that the relationship between them is complex.

With good results, video has been used extensively in teacher education as a tool for student teachers' reflection-on-action (Chan & Yau, 2021; Coffey, 2014; Gaudin & Charliès, 2015; Radloff & Guzey, 2017; Rich & Hannafin, 2009). Some studies have been conducted on how in-service teachers can develop their PCK using video-based reflections. Alonzo and Kim (2016) explored video-stimulated interviews to elicit in-service physics teachers' PCK, particularly as used in action. Chan and Yung (2015) investigated how in-service teachers develop their PCK through reflection-in-action with the support of video. Krepf et al. (2018) also used video-recorded lessons to capture teachers' analyses related to PCK components suggested by Shulman (1987). However, they used other teachers' lessons for the video-based reflections instead of their own. The findings showed that expert teachers activated both content knowledge and pedagogical knowledge intensively and combined both kinds of knowledge in line with Shulman's amalgam thesis.

### CoRe and Video-Based Reflection in Combination

Research demonstrates that using video as a reflection tool to capture and develop PCK is successful for both student teachers and in-service teachers. As previously written, CoRe has proven to be a valuable tool for developing PCK. Nilsson and Karlsson (2019) have investigated how CoRe, in combination with video-based reflection, can be used to gain student teachers' professional knowledge. Their results indicated that the combination of the tools is successful in building and structuring student teachers' reflection-on-action, as they could connect their reflections to components of PCK and see connections between them.

Based on the previous experience of combining CoRe and video-based reflections described by Nilsson and Karlsson (2019), we used the combination of the tools to capture in-service teachers' PCK in SD.

## Method

### The Empirical Context

The Swedish curriculum for upper secondary school consists of one overarching section that covers the entire education. In addition to this general curriculum, there are specific curricula for individual subjects. SD is incorporated into several subjects' curricula, including biology and social studies. There is also a subject called Science, which takes an interdisciplinary approach with a particular emphasis on SD. As mentioned in the introduction, sustainability and environmental issues are important topics in our world today. SD expresses a possible and desirable future where school and education are important factors. The overall curriculum highlights this in the following way:

> The environmental perspective in teaching should give the students insights so they can contribute to preventing harmful environmental impacts and acquire a personal approach to the overall and global environmental issues. The teaching should highlight how society functions and how our way of life and work can be adapted to create sustainable development. (Swedish National Agency for Education, 2023a, p. 4).

As such, SD must permeate the entire education. However, the Science curriculum further stipulates that teaching should allow students to develop their knowledge and skills concerning SD (Swedish National Agency for Education, 2023b).

> Questions about sustainable development: energy, climate and ecosystem impact. Ecosystem services, resource utilisation, and the carrying capacity of ecosystems. (Swedish National Agency for Education, 2023b).
> Different aspects of sustainable development, for example, in terms of consumption, resource distribution, human rights, and gender equality. (Swedish National Agency for Education, 2023b).

As such, the Swedish curriculum emphasises the three interlinked dimensions of SD: society, environment, and economy.

## Research Design and Data Collection

In the study, 11 in-service teachers teaching science participated. The teachers worked in two upper secondary schools (students aged 16–18 years) in different parts of Sweden and taught students attending different study paths. The first author personally contacted the science teachers after the school principal's approval. All 11 teachers were introduced to the CoRe tool and the theoretical framework of PCK. This introduction included the various aspects of RCM through a presentation, a book chapter about PCK and CoRe, and an empty template of the CoRe.

The design of data collection included several subsequent steps. Figure 3 illustrates the steps of the data collection and how they are connected.

The teachers were given the task of filling in the CoRe template independently. The content area or theme given beforehand to the teachers by the researchers was SD. However, within the broad theme of SD, the teachers chose the topics themselves. The teachers individually formulated three to eight Big Ideas for teaching SD and responded to the eight prompts for each Big Idea. When the CoRe was filled out, the teacher sent it to the first author. A semi-structured individual interview followed, where the teachers could narrate and reflect on their CoRe. Each interview was audio-recorded and lasted for approximately 60 min. During the interview, the teachers reflected on their Big Ideas concerning the CoRe prompts and the researchers' in-depth questions. Thereafter, the teachers performed a lesson concerning their CoRe. The teacher chose the lesson and which part of the CoRe it was connected to. The first author attended the lesson and video-recorded the teacher. The final step in the data collection was a video-stimulated individual interview, which was audio-recorded. This interview also lasted approximately 60 min for each of the teachers. During the interview, the first author and the teacher together watched the film and, on the initiative of both, stopped and talked about sequences in the film. The teachers reflected on how the Big Ideas were translated into their teaching practice. An example is when teachers saw themselves on the video they discovered and reflected on how they tried to prevent misunderstandings among students around particular concepts they covered in their CoRe. They related to the prompt in the CoRe, where they reflected on their knowledge of students' perceptions/misconceptions and how it affects their

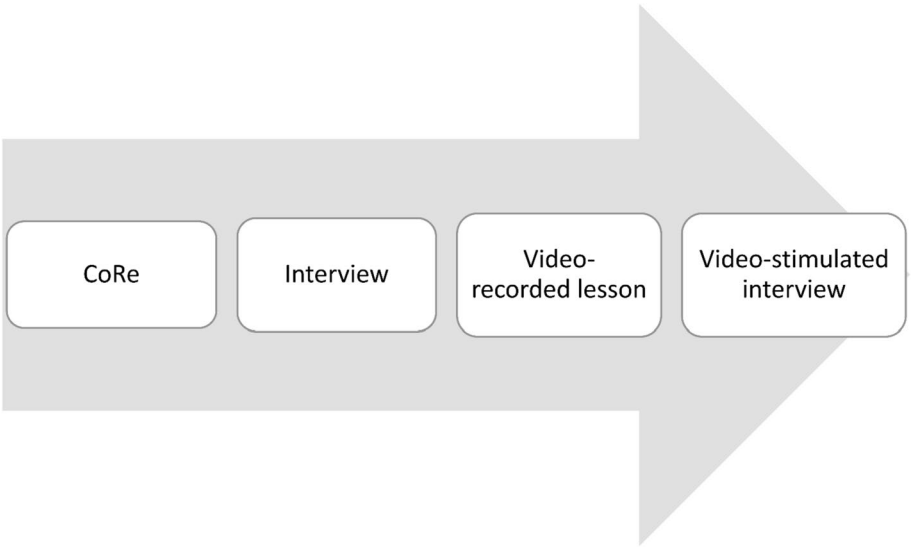


**Fig. 3** The figure shows the four interconnected steps of the research design

teaching. As such, they could see how they handled the teaching situation with their pedagogical reasoning.

## Data Analysis

All data (the CoRes, interviews, and video-recorded lessons) were collected in the teachers' mother tongue (Swedish). Data were transcribed, and the transcripts were translated into English.

The analysis was then completed in two stages. In the first stage, we (all the three authors) individually familiarised themselves with (read and re-read) the transcribed data. Then we, together in a recursive process until consensus was reached, identified sets within the data where CoRe, combined with video-based reflection, helped to capture components of teachers' PCK. The findings from the teachers are unique for each of the 11 teachers. Because of the space limit a paper entails, data from two teachers were selected to illustrate representative examples from the analysis of the 11 teachers.

In the second stage, the two teachers' data sets were analysed through qualitative content analysis (QCA) (Schreier, 2014). QCA is a flexible method that systematically reduces data and limits the analysis to the aspects relevant to the given research questions (Schreier, 2014). Using the QCA method, the chosen data from the first stage were analysed concerning the inner part of the RCM in the second stage of the analysis process. With the focus on ePCK and pPCK, RCM constituted a concept-driven coding frame.

## Findings

Examples of the findings are presented below in two parts, one for each selected teacher. Figure 2 (the inner part of the RCM) serves as a theoretical lens. The findings demonstrate the capture and articulation of the teachers' pPCK, the plan-teach-reflect cycle when the teachers enact the teaching (ePCK), and the potential development of pPCK from that specific cycle.

The two teachers are named Jacob and Elliot. Elliot and Jacob are educated, experienced science teachers who have taught science and SD for several years. They independently completed a CoRe and chose which Big Idea the lesson was supposed to be built upon. After that, they planned the lesson and fulfilled it without the involvement of the researchers. Jacob's lesson dealt with eutrophication in the Baltic Sea linked to SD. Elliot's lesson dealt with global warming linked to SD. Each part has, in conclusion, a PCK figure outlining the essence of the analysis. Finally, the findings are summarised.

### Jacob

Jacob began his video-recorded lesson by explaining to the students what he expected them to do while they watched a film about eutrophication in the Baltic Sea from a school material created by a foundation titled BalticSea2020 (Björn Carlsons Östersjöstiftelse, 2020). He sketched a structure on the whiteboard with two main headings: 'Causes of eutrophication' and 'Consequences', where 'Consequences' had three sub-headings: 'Nature', 'Human/social', and 'Economy'. He instructed the students to write down things they would hear and see on the film connected to these headings. After the students had watched the film, they were divided into smaller groups to discuss the notes they had made while watching the film. When they had compared and reflected together, the students were instructed to fill in examples under each heading on the whiteboard. Jacob ended the lesson by telling the students that they would have a whole-class discussion based on the examples they covered in the next lesson.

### Jacob's pPCK Input

In the interview, Jacob emphasised that it is essential that the students understand and reason about all three dimensions of SD (society, environment, and economy) and can apply problems with the eutrophication in the Baltic Sea based on that. He claimed it is more crucial than understanding the ecological and geographical details of how the eutrophication problem arises in the Baltic Sea.

> I want them to know what effects it can have on the environment. I want them to understand the main points. In addition, I want them to be able to connect the environmental perspective to humans and society and how we are affected in the next step by these eutrophication effects. Then there will be both a societal perspective but also an economic perspective. So, for example, if you make a living through tourism and are greeted by an algae soup with dead fish and bad bathing water, then it might not be so easy to make a living that way.

In addition, Jacob argued that it is crucial that the students understand that eutrophication is a deeper and more far-reaching problem as it occurs in a global context, and he expressed it like this:

> Eutrophication can be more of a local problem in some places, but it is also often an international issue. If, for example, you share water with several other countries and emissions from several other countries, it also affects the common ecosystem. And then it is also relevant to raise it from that perspective.

In his CoRe, Jacob further expressed why it is important for students to learn about eutrophication, as he connected it to the individual's active choice. He wanted the students to think about their food choices and the possible consequences of food production.

### Jacob's ePCK

When Jacob planned his teaching, he designed a strategy to support the students in analysing the eutrophication problem in the Baltic Sea based on the three dimensions in SD *(ePCKp)*. He planned which headings he would write on the whiteboard and that he would ask the students to analyse the film and write notes while watching the film. Jacob made a metaphor of the three dimensions (society, environment, and economy) of SD with pieces of a cake.

> I think it is like pieces of a cake, but then putting it together into a whole becomes very difficult to understand if you don't work on it separately first. Because it becomes a foundation on which to stand, it will also be a way to meet students who find it a little more difficult to see these connections right from the start. Those who understand these connections have also quite quickly helped to break it down this way and move on faster.

During the lesson, when the film about the Baltic Sea was played, Jacob stopped the film from time to time and asked questions to support the students in analysing and reflecting *(ePCKt)*. This way, he gave them support and a direction in the analysis. He also used the technique of stopping the film and repeating important facts that were brought up in the film. An example was that a single large pig farm produced as much excrement per year as the inhabitants of a medium-large city. Jacob reflected *(ePCKr)* on the problem with large farms and that too many nutrients end up in the wrong place in very large quantities. He chose to stop the film right here and repeat this fact. The reason for this was that he wanted the students to gain an understanding of the complexity and also to propose alternatives for action.

> We didn't have the same problem when we had small farms. You could technically raise the same number of pigs in small businesses and farms to reduce nitrogen and phosphorus emissions. It is something that I hope the students will be able to reason about. It is not something I want to give them immediately, but I want them to succeed in reaching it themselves.

Jacob reflected *(ePCKr)* on his video-recorded lesson and confirmed that the arrangement of film analysis and group discussions was good when he saw how active the students were in filling in what they had learned about eutrophication linked to the three dimensions of SD. Jacob noted that the film he had chosen had interested the students. The film was interesting and captured the gravity of the effects on nature in a poignant way. Another advantage of the film, Jacob reflected, was that much of the content reflected both natural and social consequences, which also favoured the structure he had made on the whiteboard.

### Jacob's pPCK Output

When Jacob reflected, he felt he was missing the vital role of politics. In the future, he wants to put it in relation to individual choice to give the students that perspective:

> It is about seeing the whole, how society affects from top down; so, it is not just what we eat and consume, but also what politics and the market economy set for the rules of the game.

He also connected politics to his CoRe and expressed how he will deepen his teaching in the future with a reasoning about the role of politics:

> I think about the question: what do you expect students to learn about this particular Big Idea? What I have not written in my CoRe is politics. I think I will be more significant and highlight the politics. That they are on the track that the political game and political issues often put sticks in the wheel when it comes to fixing the problems. It is also the cause of many of the problems.

Finally, to summarise part one, the main findings regarding Jacob's pedagogical reasoning are presented in Fig. 4.

### Elliot

Elliot's video-recorded lesson contained three main aspects: topical connection, local anchoring, and instilling of hope. During the first part of the lesson, Elliot taught about the consequences of global warming, depending on how many degrees of warming it will be in the future. In his CoRe, in the box for the first statement concerning what he expects students to learn about this particular Big Idea, Elliot wrote:

> The students must understand why it is important that the global temperature rise is limited to 1.5 °C.

Elliot linked the goal of a maximum temperature increase of 1.5 °C to the United Nations' global goals and the ongoing climate summit. In the second part of the lesson,

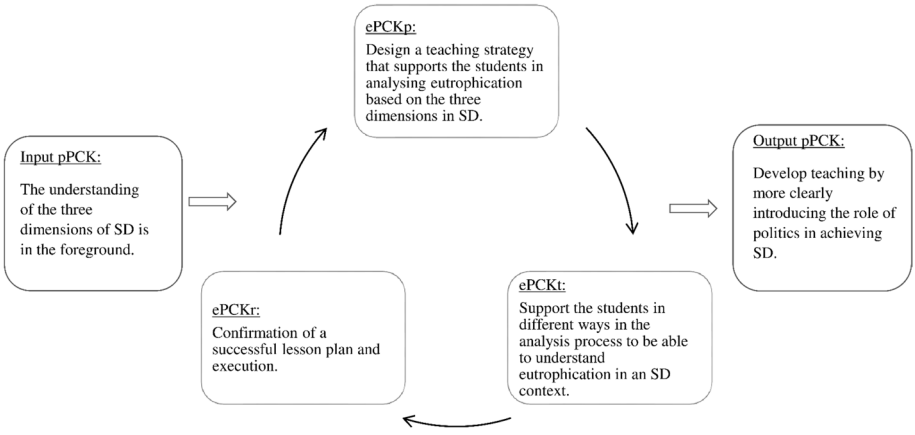


**Fig. 4** Jacob's input pPCK, pedagogical reasoning in the ePCK plan-teach-reflect cycle, and output pPCK

Elliot carried out activities to instil hope and create a belief that if we act together, we can limit the temperature increase to 1.5 °C.

### Elliot's pPCK Input

Elliot was convinced that it is crucial in teaching to both strengthen students' theoretical knowledge of SD and support students' empathy for other people, developing their ability to build solidarity. Elliot put it this way in his CoRe:

> They must understand with both brain and heart the importance of the goal and that it is possible to achieve it.

The underlying pPCK of Elliot also included that many students feel a sense of hopelessness and pessimism about the future due to global warming. These feelings risk leading to resignation and thus to reduced learning, Elliot believed, and he expressed it like this:

> It is easy to understand intellectually, but you also have a soul life. The student can feel that it will not succeed – so my intellectual self believes in it, but my emotional self does not.

He continued:

> That is what I mean by the heart: you do reward things for others, not just for yourself. I can choose what my loved ones, my family, my children and grandchildren, and others on the globe can benefit from in the future.

Elliot also expressed that hopelessness and pessimism can lead to students denying research on global warming. That is another reason for the importance of teaching students to understand the importance of the goal with the heart. It is necessary to turn hopelessness and pessimism into action and optimism, Elliot argued.

### Elliot's ePCK

Elliot expressed in his pPCK that students can be in denial about global warming, that the temperature measurements are experienced as far away and, therefore, they do not concern themselves. To help students understand the seriousness of global warming, Elliot planned his lesson (*ePCKp*) to present local statistics. Elliot believed that knowledge that gives an insight into how serious the situation is, even for students themselves, combined with a sense of hope, leads to action, and the world needs action-oriented people to deal with global warming and achieve SD. Therefore, Elliot planned (*ePCKp*) the first part of his lesson so that the students would understand the seriousness and the second part of the lesson to create hope and action. During the first part of the lesson (*ePCKt*), Elliot told a true personal story about an older man who lives in the same town as them and who has been taking temperature measurements near the school for decades. Elliot reinforced the local anchoring by showing pictures and a map of where the measurements have taken place. The measurements showed that the temperature increase in their town is even higher than the average global measurements. Elliot reflected (*ePCKr*) that the local anchoring and clarity means that even those students who previously denied the seriousness of global warming now understand. He expressed as he saw himself on video, teaching about the local measurements the man had completed:

> Here we have his summary from last year. It is crystal clear. That is what I mean, that then you get an anchoring. He can see this: 2.3 degrees above normal. We have a higher increase here than in other places. Especially against climate deniers, this is good.

During the second part of his lesson, Elliot planned teaching activities (*ePCKp*) intending to give students a sense of hope for the future, that global warming can be limited. Elliot completed two activities during the second part of the lesson (*ePCKt*). One was about the students having to reason together and come up with different measures that we humans (both on an individual and societal level) can do to limit global warming. The second activity was a valuation exercise where the students had to stand on a scale between one and ten, depending on how certain they are that the world will be able to limit warming to 1.5°C. The students justified why they stood where they did. Elliot participated (*ePCKt*) in the exercise and reasoned that he had great hope for the future. He linked back to everything the students came up with about what we can do together to prevent global warming. Elliot's participation in the valuation exercise, where he argued optimistically about different courses of action, was based on a well-thought-out strategy (*ePCKp*). He thought his arguments and optimism could make students more hopeful and active in SD (*ePCKr*).

After the work with CoRe and video-based reflection, Elliot concluded that it is crucial when teaching SD, and in particular global warming, to be sensitive as a teacher and to place great importance on understanding the students' perceptions and misconceptions.

> One of the most important things is to interpret the students during the lesson and for the next lesson. And that they understand that I interpret them. I try to meet them that way. My self-reflection is important. How do the students receive it? Do they get it or not? It is partly about the students understanding the concrete, but through a little subtlety also understanding the whole and the context.

### Elliot's pPCK Output

Elliot believed that the CoRe has been and can continue to support him in teaching:

> I missed that you cannot easily describe exactly what and why you do a certain thing. The CoRe could therefore function as a manual you keep in your mind. Then you could talk to someone about it afterward. Why am I doing this? What is the thinking? I have a rather unspoken way of sometimes thinking. Of course, I know which concepts and other things to work with, but why do I do it this way?

The CoRe-tool and video-based reflection allowed Elliot to express what, why, and how he wanted to carry out his teaching. He felt the confirmation of his chosen methods to reach what he wanted. Therefore, he reasoned about additional aspects that could strengthen his teaching even more to reach the goal he set up, namely that the students understand the importance of the goal with their hearts and mind. He reasoned that he wanted to introduce more reality-related reasoning, such as climate refugees, into the teaching. Elliot feared that climate refugees would increase in the future, and he reasoned that the students need to understand what that could mean for the affected individuals and the whole earth.

> The main theme was limiting global warming to 1.5 degrees. I think we have reached that the students understand the importance of the goal with their heart and mind and that it is possible to achieve it. After all, it would have been good if you had had a tal-

ented person with you who was linked digitally, someone who worked with climate refugees.

Finally, to summarise part two, the main findings regarding Elliot's pedagogical reasoning are presented in Fig. 5.

## Summary of the Findings

The findings showed that the reflective tool CoRe and video-based reflection supported the teachers' pedagogical reasoning when teaching SD. The work with CoRe helped teachers to make explicit why they had chosen a certain content in their teaching in SD. Jacob emphasised that it is vital for the students to understand the three dimensions of SD (environment, society, and economy) and how they interact in a complex way. This was the reason for why he chose the content 'eutrophication in the Baltic Sea'. The Baltic Sea's geographic location was critical, as several countries have a coastline to the Baltic Sea, affecting the ecosystem. The economic and societal dimensions of SD can therefore be problematised in education more clearly. Elliot chose the content of global warming in his teaching in SD, as global warming and climate change are highly topical issues in the global societal debate.

Apart from the teaching content, the teachers emphasised the implementation of ePCK in their pedagogical reasoning. Both CoRe and video-based reflection supported them in the ePCK process: plan-teach-reflect. Jacob emphasised that it is important to construct and design the teaching so that it is possible for the students to understand the three dimensions of SD and be able to connect them, as in this case, eutrophication in the Baltic Sea. Therefore, he performed a collective analysis of a film with the students concerning eutrophication in the Baltic Sea. He also arranged discussions in smaller student groups based on the three dimensions of SD and then had a concluding discussion with all the students. Elliot's teaching strategy included presenting local statistics on global warming to make the students to understand that global warming also concerns them and to counteract climate denial. Elliot's teaching design also included activities to be responsive to the student group and instil hope for the future and options for action.

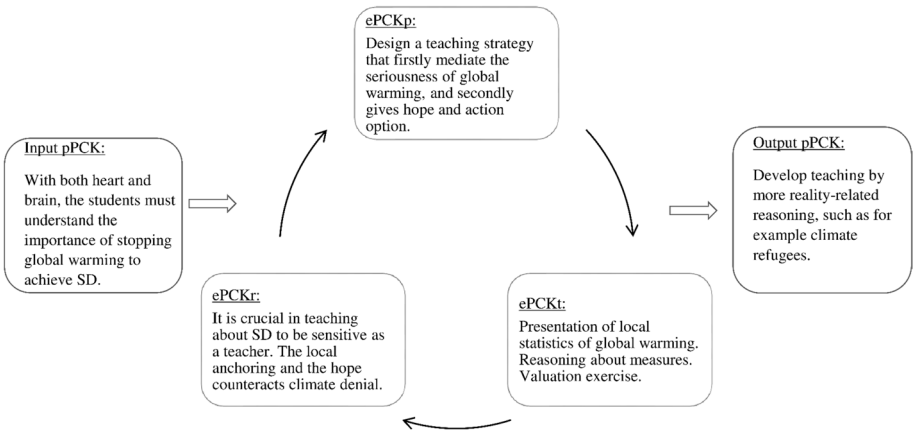


**Fig. 5** Elliot's input pPCK, pedagogical reasoning in the ePCK plan-teach-reflect cycle, and output pPCK

The CoRe and video-based reflection supported both teachers in catching and articulating their pedagogical reasoning: The pPCK they had when they entered the project and the three phases (plan-teach-reflect) that formed their ePCK. This clarification supported the teachers in expressing possible and desirable development of their teaching. In his pedagogical reasoning, Jacob said that he wants to develop his teaching to introduce the political role for achieving a SD. Elliot expressed in his pedagogical reasoning that he wants to develop his teaching with even more reality-related reasoning, such as climate refugees. The work with CoRe and video-based reflection was therefore not only a support for the teachers to catch and express their chosen content and implementation in their teaching in SD but it also led to the teachers being able to deepen and create opportunities for the development of their pPCK.

## Discussion and Conclusion

As has been noted, teachers' competence is crucial for the teaching of SD (Timm & Barth, 2021). Therefore, we argue that teachers must be provided with the best conditions to continuously deepen and develop their competence to teach about issues concerning SD. This study investigated how the reflective tool CoRe, in combination with video-based reflections, contributed to the capturing and development of teachers' ePCK and pPCK concerning SD. The teachers' reflections support the assumption that processing the experiences of each unique teaching situation enriches a teacher's pPCK. Earlier research (Nilsson & Karlsson, 2019) concluded that CoRe, combined with video-based reflections, was fruitful for student teachers' development of PCK.

> As such, the CoRe, together with the video annotation tool, proved to be successful in scaffolding and structuring student teachers' reflections, and consequently contributed to capture aspects of their PCK, important for their learning to teach science (Nilsson & Karlsson, 2019, p. 434).

The findings from this study illustrate that a design where in-service teachers work with CoRe, accompanied by video-based reflections on their teaching, supports them to express their pedagogical reasoning and make fruitful reflection-on-action. This study shows how CoRe and video-based reflection can be helpful, not only in teacher education but also for in-service teachers in their pedagogical reasoning. The conclusion is that the use of tools for reflection (i.e. CoRe and video) provides opportunities for teachers to make the often tacit knowledge of practice explicit and help them begin to identify aspects within their own practice that are important for further development for teaching SD. Therefore, we suggest that science teachers should be provided with reflection tools such as CoRe and video and be supported to use these tools in collegial settings.

Behling et al. (2022a) recommend using the plan-teach-reflect cycle to develop pPCK, as their empirical study showed it to be fruitful. In line with Behling et al. (2022a), we also recommend the use of the plan-teach-reflect cycle for the development of teachers' pPCK, preferably with the CoRe tool in combination with video. Making the ePCK explicit, as in the plan-teach-reflect cycle, helps teachers to reflect and emphasise why they teach the way they do and why they choose certain content.

The outermost layer in the RCM (Fig. 1) frames teachers' professional knowledge. Besides content knowledge, pedagogical knowledge, knowledge of students, and assessment knowledge, it also contains curricular knowledge. In the Swedish curriculum, there

are statements about SD that teachers must relate to and comply with. For example, the curriculum states that teaching should give the students insights about how society functions and how our way of life and work can be adapted to create SD (Swedish National Agency for Education, 2023a). Both Jacob and Elliot highlighted in their teaching how society works and how our way of living and working can be adapted to create a sustainable future. Jacob related it to eutrophication and Elliot to global warming. Both Jacob and Elliot designed their teaching to obtain the expectation in the curriculum; the standpoints in the curriculum were a part of their pPCK. These examples demonstrate how the different realms in the RCM are interwoven, unique, and complex.

The findings showed that the tools provided opportunities to capture and articulate the meaning of teachers' different aspects of PCK, including ePCK (containing ePCKp, ePCKt, ePCKr), as well as pPCK. Also, the knowledge exchange between ePCK and pPCK was made explicit. The way we have used the inner realm of the RCM as an analytic tool also makes an important contribution to how the RCM can be used to identify and capture PCK for teachers. This contribution can be seen as a response to Mientus et al.'s (2022) argument that the RCM can function as a meaningful theoretical lens for conceptualising links between teaching practice and PCK development.

The findings in this study were illustrated by two of the eleven teachers involved, as the two teachers served as examples of the whole group. Consequently, the outcomes do not provide any basis for generalising results to a wider population. While this may be considered a limitation, conclusions, and implications can be drawn from how the CoRe and video-based reflection can be helpful for teachers in their pedagogical reasoning when teaching SD. These conclusions could also be used in wider contexts, for example, by teacher educators preparing student teachers for teaching science.

Future studies could explore how a larger number of teachers develop their teaching of SD as well as provide perspectives from teachers in countries other than Sweden, thereby broadening knowledge about how science teachers can develop their pPCK and ePCK for teaching SD.

Finally, this study's main contribution is that using RCM as a theoretical lens and CoRe and video-based reflection to support teachers' pedagogical reasoning can be beneficial to develop the teaching of SD. And that, in turn, can hopefully be a small piece of the puzzle to create a sustainable future for our shared world.

## Appendix. Interview protocols

Interview 1: Individual semi-structured interview.

1. What we focus on is the teaching content about sustainable development. Tell me about your Big Ideas and what you thought when selecting the ones you made, in terms of content area and number.
2. If we now start with your first Big Idea, go down in the chart and look at what you have written in the different boxes for the various prompts. We begin with the first and go down, so feel free to tell me a little about what you thought about each.
3. Then we take your next Big Idea and do the same; I would like to hear what you have thought here. (Continue in the same way until all Big Ideas are accounted for).

Interview 2: Individual video-stimulated interview.

1. Describe how you planned your lesson based on your CoRe. (We watch the film together, and on the initiative of both, we stop and talk about sequences in the film.)
2. I ask you now to summarise your reflections. What is the most important thing you take with you?

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**Data Availability** Data availability can be shared on request.

## Declarations

**Ethics Approval** Data collected and analysed within the project contained personal information. The handling of this data followed the ethical guidelines of scientific research and the guideline set by the Ethical Review Authority; moreover, the study was approved by the ethical committee at the university. All participating teachers gave their consent to participate in the project and agreed to share their CoRes for research purposes. They also agreed on the audio documented interviews and video-recorded lessons. All handling and presentation of data were anonymised.

**Conflict of Interest** The authors declare no competing interests.



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