Journal of Biological Education

ISSN: 0021-9266 (Print) 2157-6009 (Online) Journal homepage: http://www.tandfonline.com/loi/rjbe20

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To cite this article: Martin Scheuch, Tanja Panhuber, Silvia Winter, Julia Kelemen-Finan, Manfred Bardy-Durchhalter & Suzanne Kapelari (2018) Butterflies & wild bees: biology teachers' PCK development through citizen science, Journal of Biological Education, 52:1, 79-88, DOI: 10.1080/00219266.2017.1405530

To link to this article: https://doi.org/10.1080/00219266.2017.1405530

Published online: 26 Feb 2018.

JOURNAL OF BIOLOGICAL EDUCATION, 2018
VOL. 52, NO. 1, 79–88
https://doi.org/10.1080/00219266.2017.1405530

Butterflies & wild bees: biology teachers' PCK development through citizen science*

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ABSTRACT

Citizen science is a rapidly growing emerging field in science and it is gaining importance in education. Therefore, this study was conducted to document the pedagogical content knowledge (PCK) of biology teachers who participated in a citizen science project involving observation of wild bees and identification of butterflies. In this paper, knowledge about how these biological methods can be taught to students is presented. After two years in the project, four teachers were interviewed and their PCK was captured in the form of content representations (CoRes) and Pedagogical and Professional-Experience Repertoires (PaP-eRs). These results can help future citizen science projects to link their activities to the school curriculum. But not only success can be reported: although one of the project team's aims was to make the Nature of Science accessible to the teachers and students in the course of the project, the teachers did not take this aspect into account. This paper discusses the possible reasons and proposes various strategies for improving citizen science in the context of school biology learning.

KEYWORDS
Pedagogical content knowledge – PCK; citizen science; biology teachers; observation; species identification

1. Introduction

'Nature in your backyard – Citizen Science for schools' was a two-year citizen science project starting in October 2014, which was conducted in cooperation with conservation scientists at the University of Natural Resources and Life Sciences, Vienna and 16 Austrian schools. The aim was to document biodiversity in a range of urban and rural gardens to investigate the interrelation between garden management and the occurrence of certain groups of animals. Participating students interviewed garden owners and observed hedgehogs, a small set of butterfly and bird species as well as the foraging behaviour of wild bees (Winter et al., 2016). They used various methods and tools provided by the scientists to conduct the garden surveys. According to Phillips et al. (2014), the project can be classified as a contributory Citizen Science project as the research topic and questions, the hypothesis and the methodology of data acquisition were defined by the scientists whereas the citizens contributed by collecting data. The analysis is then again part of the scientists' work. In return, the students participating in 'Nature in your backyard' had the opportunity to learn more about the value of biodiversity

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*This paper was presented at the ERIDOB conference 2016.

and gardens as habitats for selected wildlife species (Panhuber 2016, 47 f). Moreover teachers attended workshops, focusing also on the Nature of Science (NoS, cf. Lederman 2007) – in particular on the Nature of Biology (NoB, cf. Kloser 2012). Implicit inquiry-oriented approaches fail to promote students NoS conceptions (Abd-El-Khalick 2012; Lederman 2007), therefore science educators constructed reflective workshops focusing on central aspects of NoS and NoB (namely the distinction between observation and inference (Lederman 2007) and the difficulties of variation within a species for identification (Bardy-Durchhalter, Scheuch, and Radits 2013)).

In this educational study, our focus is on participating teachers as they are supposed to act as mediators between scientists and students (Ibid.). Teachers are expected to motivate and support their students in collecting data. However, they also have to consider the national curriculum and educational goals. Moreover, personal and professional objectives for participating in this project do have an impact on how teachers approach their task as mediators. Thus it is both highly interesting and complex to focus on the teacher's knowledge and learning in the course of such a Citizen Science project.

We focused on two observation activities as scientific practices applied in biology research (Eberbach and Crowley 2009; Mayr 1982, 28–32), which were prominent in the data acquisition process during the project. These two activities were observation of foraging flight durations and butterfly identification (Bromme et al. 2004; Mayr 1969).

2. Citizen science and teacher knowledge

In the course of citizen science projects, participating volunteers have the opportunity to gain a better understanding of ecological concepts and to increase their knowledge about species (Bela et al. 2016; Kelemen-Finan and Dedova 2014). As for citizen science in school settings, focusing on local environments, enabling autonomous learning and working outside can lead to better attitudes towards nature conservation and scientific research (Collins 2014). However, this does not automatically translate into students taking action in their spare time, but can positively influence their attitudes valuing biodiversity and interests in nature in the long-term. Providing outdoor learning during school hours is very important for achieving these goals of environmental education.

2.1. Observing organisms, identifying species

Students and teachers made scientific observations (Eberbach and Crowley 2009) to document bee behaviour and to identify various target species (Bromme et al. 2004) in this project. Both tasks posed challenges to the participants.

Observation is the basement for many scientific endeavours, for this reason it has to be considered in school science (Lederman 2007; Osborne et al. 2003). Eberbach and Crowley (2009) attach a main obstacle of students` understanding of the scientific method of observation comparing scientific observations to everyday observations.On one hand scientists apply specialist knowledge and a disciplined view, linking their observations to theoretical concepts. They have a focus according to their hypothesis and for correlations that can be interpreted later. On the other hand, students, are often guided by chance in their observations and draw conclusions rashly, seldom distinguishing between observation and inference (Lederman 2007). Everyday knowledge is fundamental to their observations and therefore often very idiosyncratic.

A second challenge for students is to identify species. Species identification is done scarcely in schools (Randler and Bogner 2006) for various reasons: e.g. the species richness of study sites is too much to cope with. Another difficulty is the similarity between different species as well as variation within one species (Bardy-Durchhalter, Scheuch, and Radits 2013). Without knowledge about relevant features, laypersons have difficulties to make reliable decisions when it comes to naming species correctly. Teachers in Austria hesitate to integrate identification activities into their lessons for the very same reasons (Kelemen-Finan and Dedova 2014). Due to these findings, only a small set of target species were selected for 'Nature in your backyard'. Teachers and students were supported by scientists and science educators to ensure that the above-mentioned obstacles are mastered. The Austrian science curriculum asks students to become scientifically literate, i.e.to understand fundamental scientific concepts and how scientific knowledge is gained. Supporting their students in these observations were the duties of the teachers. Therefore we examined teachers' professional knowledge conceptualized as pedagogical content knowledge (PCK) (Shulman 1986).

2.2. PCK as professional and implicit biology teacher knowledge

PCK was introduced to educational studies in the mid-eighties by Shulman (1986). It refers to the specialist knowledge that distinguishes a biology teacher from a sole biologist. It is closely linked to content knowledge and builds upon it, but includes additional knowledge and skills like the educational purpose of a specific topic, the curriculum, the students' thinking and preconceptions of the respective topic, how to evaluate learning as well as values and beliefs in teaching this topic (Magnusson, Krajcik, and Borko 1999). One aspect was especially stressed by Loughran, Berry, and Mulhall (2012): PCK is mostly implicit knowledge and developed within teaching practice.

Together with science teachers, Loughran, Berry, and Mulhall (2012) developed a useful approach to structure and visualize ideas about teaching a specific topic. According to this conceptualization, several questions about teaching the Big Ideas (what is important and why, difficulties, student preconceptions, methods etc.) of this topic are worked through. The result is a grid, the so called 'Content Representation' (CoRe). Additionally, Pedagogical and Professional-Experience Repertoires (PaP-eRs) help to understand the connections between the grid cells in the form of condensed teaching stories. These two results taken together are the Resource Folio, which represents the participating teachers' PCK, a collective knowledge-base concerning the teaching of a particular topic. The concept of PCK is ever developing, nonetheless it is 'useful to the extent that it can stimulate the thinking and scholarship of others.' (Shulman 1999, XI).

3. Research aims and question

The aim of this study is firstly to portray the development of teacher's PCK when supporting students to identify species and to manage the transition from every day to more scientific observations. Secondly, we want to learn more about how teachers tackle the tension between fulfilling scientists' expectations and achieving their own educational goals while participating in this Citizen Science project. Thus the research question was: What PCK in conceptualization of CoRes and PaP-eRs becomes visible after participating in a Citizen Science project that involves observing wild bees and identifying butterflies?

4. Methodology

In this qualitative study, data was collected via guided interviews with teachers who participated in the project 'Nature in your backyard' for two years. We only selected teachers from upper secondary schools in order to keep teacher education background homogenous. Four of seven potential interview partners agreed to participate in the study. An overview of conducted interviews is given in Table 1.

We decided to use the PCK model proposed by Loughran, Berry, and Mulhall (2012) in which teachers define the Big Ideas of a science topic first and are then asked to elaborate on them along the questions given in the CoRe. The analysis roughly followed a framework analysis (Ritchie, Spencer, and O'Connor 2003), in which the conceptual framework was determined by the CoRes' categories. To analyse the data via qualitative content analysis (Mayring 2007), the interviews were first transcribed and then coded with the help of atlas.ti 7 software using both deductive categories (derived from Loughran, Berry, and Mulhall 2012) and inductive categories emerging from the interviews (Mayring 2007). Two overall CoRes which portray the compiled results of individual CoRes for the topics 'observation of wild bees' foraging and nesting behaviour' and 'identification of butterflies and knowledge about local butterfly diversity' were reconstructed. They represent the synthetic knowledge of the four teachers. The two selected CoRe columns presented in the results section are dedicated to

Table 1. Overview of interviews.

	Interview 1 (I1)	Interview 2 (I2)	Interview 3 (I3)	Interview 4 (I4)
Sex	Female	Male	Female	Male
Teaching experience according to Schneider and Plasman (2011)	Much experience in science teaching	Some experience in science teaching*	Much experience in science teaching	Much experience in science teaching
Participating classes (grade)	10th, 12th	10th, 11th, 12th	6th, 10th	11th
Enquired CoRe-topics	Wild bees	Wild bees, butterflies	Wild bees, butterflies	Butterflies

*Plus additional experience in teaching science at university.

behavioural observation of wild bees while species identification dominated the work with butterflies. Additionally, PaP-eRs were written to illustrate key points about how the individual teachers supported their students in making observations and in identifying species and which aims they were following. Teacher quotations and paraphrases are indicated with I1 to I4 in brackets (see also in Table 1). Taken together, CoRes and PaP-eRs represent the Resource Folio which displays the participants' PCK.

5. Results

Results are presented in the following two tables. Table 2 shows the wild bee observations and Table 3 the identification of butterflies. These two CoRe columns summarize the results of all four teacher interviews, but are only part of the original CoRes. The original CoRes can be looked up in Panhuber (2016, 31–46, written in german) or requested from the authors. In Sections 5.3 and 5.4, we present two selected PaP-eRs. These PaP-eRs represent more of the personal PCK of the teachers. The first PaP-eR illustrates the topics on observation and identification and the other one deals with teaching the value of biodiversity as an educational goal.

5.1. Observing wild bees

To give the reader an impression of the original CoRe, the five Big Ideas are presented briefly:

- honeybees and wild bees differ in their way of living
- wild bees collect pollen for feeding larvae
- wild bees are important pollinators
- wild bees can be supported with structures for nesting in gardens
- observing wild bees foraging and nesting behaviour with bee houses.

The first two big ideas were important for activating prior knowledge about the well-known honey bees and to establish differences and similarities to wild bees. Knowledge about the development and nesting of wild bees was needed to understand their foraging behaviour. The next two big ideas linked wild bees' importance and ways to support them, the last one was connected to the main project activities by the students and is presented in Tab. 2.

5.2. Identifying butterflies

In the second CoRe the following six Big Ideas were sketched by the teachers:

- life cycle of butterflies
- morphology of insects using the example of butterflies
- from caterpillar to imago
- ecological aspects of butterflies
- threats for local butterfly diversity

Table 2. Big Idea 'observation of the wild bees'.

BIG IDEA question	Observing wild bees foraging and nesting behaviour with bee houses
What you intend the students to learn about this idea	• Observation, understanding of and fascination for behaviour of wild bees: Choice of nesting site depending on the species and abiotic factors, construction of brooding cells, foraging for pollen, hatching. • Which bees will nest in bee houses; where do they normally nest? • Holometabolous development. • Learning how to observe patiently and accurately.
Why it is important for students to know this	• Observation of nesting behavior is one way to foster fascination for these animals. • They understand the connection to nature conservation: certain structures like deadwood are needed to increase or maintain biodiversity of wild bees.
Difficulties/limitations connected with teaching this idea	• Due to the short (early) period of breeding activities – students missed out observing wild bee foraging for pollen. • Bee houses sometimes did not colonize or were infected by fungi or parasites → students disappointed. • Fear of bee stings and bee allergies. • Lack of patience and engagement during observing activities. • Difficulties in counting the brood cells.
Knowledge about students' thinking which influences your teaching of this idea	• Some students know bee hotels as 'insect hotels' but do not know that wild bees use them. • Fear of bees must be tackled: concentrating on wild bees, fostering fascination for these organisms. • Difficulty of grasping the idea of bees hibernating as larvae – their knowledge of honey bees that collect honey as winter fodder interferes.
Other factors that influence your teaching of this idea	• Bad weather during observations and lack of time in biology lessons has a negative impact. • It is important to trust in students' abilities to make reliable observations; however, checkups are necessary once in a while. • Getting one's own bee house boosts motivation. • Help students to connect their individual observations to theory.
Teaching procedures (and particularly reasons for using these)	• Preparation: Convey important background information (nesting behavior and development); show pictures, talk about what is to be expected during observations. Present bee house and explain data entry form, observe together with students. • Observation and reflection:Students can now observe and document nesting behavior on their own. Let students explain what they have observed to one another. Talk about student thinking and problems in class.
Specific ways of ascertaining students' understanding or confusion around this idea	• Looking at data entry forms; talking to students to check understanding. • Check up on students during observations.

Table 3. Big Idea 'identification of butterflies'.

BIG IDEA question	Identification of butterflies and knowledge about local butterfly diversity
What you intend the students to learn about this idea	• How to identify the target butterfly species. • Background information on target species (e.g. distribution in different habitats). • Which species frequently occur in gardens in schools' vicinity? • How to differentiate between butterflies and moths due to their antennae. • Basics of speciation and species concepts.
Why it is important for students to know this	• To foster interest in butterflies and observing nature. • Knowledge about biodiversity and being able to identify frequently occurring butterflies should be part of general education.
Difficulties/limitations connected with teaching this idea	• Learning how to identify species needs a lot of time and continuous practice. • Students who invested much time only observed few species during the time set for observation. • Observation dependent on good weather conditions. • Even after good training a possibility of confusion between species is still given.
Knowledge about students' thinking which influences your teaching of this idea	• Especially younger students sometimes think that all butterflies belong to one and the same species. • Kids are impressed even by few butterfly species they can identify. • More advanced students prefer more global approaches → higher order learning, e.g. not about single species but overall principles.
Other factors that influence your teaching of this idea	• Knowledge about different species is important but rarely learned in school as it is not explicitly mentioned in the curriculum. • Specially designed teaching material was appropriate to increase students' and teachers' knowledge about butterfly taxonomy. The activities 'clustering pictures' and 'identifying butterflies' were informative and entertaining and supported them to develop a sound knowledge base about target species.
Teaching procedures (and particularly reasons for using these)	• Preparation: Using material for practicing identification of the target species (Photos, species quartet card game, butterfly app) in class; students test one another; guessing games: which butterfly is it; talk about defining features of each species; cluster species due to similarities. • Preparation by the project team: Outside, students practiced catching and identifying butterflies together with scientists. • Identification and reflection: Students observe and identify the target species in small teams on their own according to the data entry form. Students discuss defining features.
Specific ways of ascertaining students' understanding or confusion around this idea	• Let students match pictures to the right species. • Due to the nature of the project (enjoying practical activities was key element), students were not formally tested but content was discussed orally when entering data into the database.

- identification of butterflies and knowledge about local butterfly diversity.

The first three big ideas are strongly linked to the Austrian state curriculum. The next two form links to environmental education and conservation topics, the last (presented in Table 3) tackles the main activity within the project.

In both CoRes teachers report that it is important to work with the students on the theoretical background. Only then can observation activities be connected with theory. In the first PaP-eR below, the importance of theoretical input is stressed via some quotes. In the second PaP-eR, the overall aim of the teachers about biodiversity education is presented. These PaP-eRs add information to the CoRes and assemble additional inductively found results.

5.3. PaP-eR: supporting observation and identification activities

The following PaP-eR illustrates

- the view of students on insects and how this relationship developed,
- how the teachers prepared their students for the tasks and how they were able to overcome difficulties,
- the teachers′ educational motivation to participate in these activities.

First, fear of insects or prejudice against those animals had to be discussed: 'Insects are often considered pests due to their anatomy' (I3) and 'By exchanging stories, by focusing on wild bees which do not sting and by getting students to appreciate these insects' important role as pollinators, fears could be minimized.' (I1). Furthermore, background information needed to be taught to be able to understand the observations made: 'It was important to teach them about the development of wild bees, to talk about what is to be expected during the observations and to practice observing together with the students.' (I2, I1). To be able to connect theory to observed behaviour, the teachers asked questions to establish this link, e.g.: 'Why do some bees need more time to collect pollen for their brood than others? Are they lazy like Willy the bee?' (I1).

One teacher talked about how the observation activity affected her students' attitude towards these animals positively: 'My students developed a personal connection to the bee brood as they wanted to protect the larvae from predators and fungal infection. Witnessing students discuss what they have observed and to marvel at the bees' behavior was very rewarding.' (I1).

Supporting students in learning how to identify butterflies needed more preparation:

> We had a look at pictures of the target species and discussed which features are relevant, also in a playful way by guessing which butterfly it is and by playing a species quartet. It is not possible to learn how to identify species like learning facts. It is a matter of practicing to recognize subtle differences between species. This cannot be explained, it needs to be seen and practiced repeatedly. (I3)

The feeling that the project could provide aspects that are rarely addressed in regular school lessons was one of the driving forces for teachers to participate in the project:

'Species identification is often neglected in school.' (I4). 'Usually, there is just no time for it and it is not sufficiently covered by the curriculum. However, I think students should be able to identify prevalent local species.' (I2). 'Being able to identify species can further students' interest in these organisms and their interest in observing nature in general.' (I4).

The teachers reported how the students liked to apply their newly gained knowledge about butterfly species: 'Catching butterflies and identifying them was great fun for the students (I1, I2, I3). Some of them continued catching butterflies during their summer holidays.' (I3).

5.4. PaP-eR: making biodiversity relevant to students

A central goal for all of the teachers was to convey the importance of biodiversity to their students. By making observations, students could better understand the underlying hypothesis that the diversity of butterflies is related to the diversity of flowering plants and that a greater variety of flowers will shorten the time wild bees need for collecting pollen. The following section is the PaP-eR reconstructed from three of the four teacher interviews:

> Understanding and valuing biodiversity as a life-sustaining system, understanding that humans are part of this system … this is what I want students to remember. In projects like 'Nature in your backyard', students can experience diversity for themselves and only then will they be able to grasp its significance. (I1)

As an example of the value of the observation in outdoor settings was to understand the concept of biodiversity, the same teacher continued: 'One of my students finally got what I wanted to convey when –during wild bee observations – he saw a small garden with native plants which was abundant with life and another very formal comparatively lifeless one next to it.' (I1). Although teachers had concerns about how much the project could really contribute to gaining a deeper understanding of the value of biodiversity, they nevertheless thought it to be a further step to convey major principles of ecology and a more scientific worldview:

> It is difficult to convey the importance of biodiversity by observing just a few organisms. Students would have to collect data over several years and compare their findings to other ecosystems. Also, students' previous knowledge is often not sufficient to make connections and understand the bigger picture. (I4).

'However, all these observations can be pieces of a puzzle.' (I2). 'For example, students learned about the relevance of 'weeds' like stinging-nettle for caterpillars.' (I2). 'Many small steps will hopefully lead to the students developing a scientific worldview eventually.' (I1).

6. Discussion and conclusions

This study can provide future Citizen Science projects in Biodiversity research with valuable insights about professional teacher knowledge. The resulting CoRes and PaP-eRs can be seen as synthetic knowledge extracted from the interviews. Citizen science demanded linking the participating teachers' existing PCK from regular teaching with new requirements due to the Citizen Science project (Mueller and Tippins 2012). Due to the teachers' involvement in the project and workshops focusing on explicit and reflective aspects of NoS we expected to find more explicit PCK about these issues. Although learning *with* and *about* NoS was a project goal defined by the project team, this was not reported by the teachers .

Analysis of the data, and the displayed CoRes and PaP-eRs in this article revealed that teachers managed to combine project and curriculum goals concerning environmental education and to value the project's focus on specific organisms as an opportunity to support students to appreciate biodiversity. These analyses reveal that this Citizen Science project could fulfill the requirements to link science education and environmental education (Wals et al. 2014). A lot of learning goals and activities were linked by the teachers to cover aspects of the state curriculum. The four teachers' focus was therefore on recognition of different species and as such the result of the identification process and not the reflection of the methods themselves. To gain a deeper understanding of scientific practices was not explicitly stated in the interviews. Only when it came to time constraints or the need of the students to get help, these issues emerged implicitly and the teachers supported the strategies for the observation procedures. So the teachers report about the importance of connecting students' observations with theory (knowledge about the specific organisms) and the importance of the ability to differentiate species (as basement knowledge to further understanding like biodiversity and ecosystems). But the crucial differentiation between observation and inference (Lederman 2007) even if it was an important part within the workshops, was not documented in the CoRes and PaP-eRs at all. It therefore could be assumed that teaching *with* the NoS (Abd-El-Khalick 2012) was not an aim for the teachers although it is part of the framework for the Austrian curriculum. We suppose that teachers address aspects of NoS only as content knowledge about the process of science, but they skip aspects of NoS addressing a meta-perspective of science.

This chance of learning *with* and *about* NoS was missed, because pure exposure to the procedures of science does not lead to increased understanding about NoS (Sadler et al. 2010). Pure exposure to citizen science projects does not develop NoS in laypersons either, as recent studies illustrated (Jordan et al. 2011; Crall et al. 2013). Nonetheless, each one of the teachers made first steps in their PCK development about the NoS when they reflected on their support for the students in observing and identifying animals. It is possible that this result was also influenced by the contributory approach design of the Citizen Science project. Due to the restriction of the students' roles as data collectors, there was little need to link these tasks to other elements of the scientific endeavor like the development of research questions or the interpretation of the results. One recommendation for Citizen Science projects therefore is to involve the students to a higher degree in the whole process to enable them a deeper insight into the NoS.

Another recommendation concerns the state curriculum and its role for citizen science projects: To get teachers involved, scientists could make the links of the project to the state curriculum more explicit. Not only content, but also the development of competences can be offered to the teachers and their students (Eberbach and Crowley 2009).

Overall the authors can conclude that citizen science is a great approach to get schools, teachers and students involved in scientific inquiry, also to improve the integration of science education, environmental education and acting in a local context and gaining a sense of place (Wals et al. 2014). However, the professional role of the teachers has to be taken seriously into consideration in this cooperative setting.

Acknowledgements

We acknowledge financial support provided by the Sparkling Science Program of the Austrian Federal Ministry of Science, Research and Economy (BMWFW). In addition we would like to thank all NGOs and partners who provided materials and courses for the project: Swarovski Optik, Finze Group GesmbH, BirdLife Austria, Natur im Garten, Niederösterreichische Naturschutzakademie, Lanius, MA22 and Naturschutzbund Austria. Special thanks goes to all participating students and teachers (full list can be found here: http://naturvorderhaustuer.boku.ac.at/home-2/) and to our colleagues K. Plenk, B. Pachinger, S. Stadler, T. Schauppenlehner and M. Kriechbaum.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Sparkling Science Program of the Austrian Federal Ministry of Science, Research and Economy (BMWFW) [grant number SPA 05 - 098].

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