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Lights and shadows in Physics teaching. Contributions of an action research experience

Lights and shadows in Physics teaching. Contributions of an action research experience

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Abstract. The aim of this paper is to find a teacher's concerns, difficulties and knowledge construction when he begins to be part of the field of science education research. Pedagogical Content Knowledge (PCK) model and the Content Representation instrument (CoRe) offer a significant theoretical and methodological framework to carry out this kind of study using action-research perspective. Metacognitive knowledge, critical thinking and reflection were used to describe the process and changes of the teacher. Based on a particular experience carried out for the teaching of spectroscopy in secondary school level Physics lessons, a reflection is raised on the practice itself aimed at transforming the teaching task into an object of action - research for the teacher. The processes involved in the selection of the topic, the basis for the design and implementation of the practical activity and the observations of the teacher are described. The results have shown the influence of the teacher intentions and knowledge on his PCK development by means of searching for the best way to design the class for particular students in a particular context. These are a first step to lighten the shadows on the journey to become a Physics education researcher.

1. Introduction & Theoretical Framework

To be effective, Physics teachers must think not only about the subject-matter contents that they want their students to learn and how to present them but also about their students' perspectives. A better understanding of the complex demanding settings of the classrooms, has allowed teachers to teach more effectively [1]. So, Physics teacher education and research about Physics teaching become so relevant nowadays in order to overcome the gap between research and practice [2].

Science Education has had its scholarship recognition all around the world supported by several Ph.D. university programs. Thus, research in this domain of knowledge expands and permeates the particular classrooms of those who have committed themselves to the mission of becoming researchers. One typical feature of teacher education programs, even teachers training courses, is that contents are presented in a fragmented way. On one side, professional knowledge base, as generic (not content specific) and normative, are included. While, on the other side, topic specific subject-matter courses are developed by disciplinary researchers or experts. But it is rarely to find integrated proposals that encompass both types of knowledge in a coherent blended design. Nevertheless, educative community expects teachers to achieve that blended knowledge by themselves instead of helping them to develop it. Perhaps, this way of facing in-service teachers' education is not giving the expected results in Physics Education and it would explain at least one of the reasons why young people do not chose science in college studies. In this sense, the action-research model offers an excellent opportunity for teachers who want to improve their practices. However, the process of transforming a teacher into a researcher of his own practice, although it has often been claimed and promoted, is still a pending issue. Therefore, our questions for the research were: Which are the processes, stages or changes that a teacher had to deal with in his first step in science education research? How do these events affect or not his teaching of Physics? Accordingly, our overarching purpose is to study if the way that someone becomes a science education researcher could influence on the teacher's personal pedagogical content knowledge (PCK) [3]. This is in order to offer a more complete description of the model of PCK.

Initially, Shulman [4] enlightened the difference between subject-matter knowledge *per se* and subject-matter knowledge for teaching, and then it can be distinguished between a science teacher from a scientist [5]. Further reconsiderations of this model have introduced different components for PCK, and their interrelatedness, new labels and orientations to boost the research and the use of this model [6,7,8,9]. For instance, some investigations have indicated that Content Representation (CoRe) has the potential to be used for PCK development in preservice primary teacher education [10] or in preservice Physics teachers [11]. In the same way, Juhler [12] emphasizes that in order to promote the development of PCK of the preservice teachers deliberate reflection on practice can help them to integrate theory and practice in Physics teaching. The use of CoRe is a suitable tool for intervene in teacher education field of practice. Other studies [13,14] focus on the importance of the connection between different aspects of Physics teacher PCK and teacher motivation or students' achievement, showing the relevance of affective aspects for learning. Meanwhile, Wongsopawiro et al. [15] examine the identification of pathways of secondary teachers' PCK changes in a professional development program. They consider that practice and reflection are two ways to enable teachers to construct knowledge.

Many studies have researched the impact of teachers' professional knowledge on teaching quality. Particularly, Kulgemeyer and Riese [16] have shown that student teachers' PCK mediates the influence of their content knowledge on explaining performance and the important role of social psychological factors in classrooms and other intellectually demanding settings.

In summary, in most of these cases, preservice or inservice formal teaching programs were used as sources of information [8,17,18]. Instead of that, in this study, the attention was focused on the process of action - research of a Physics teacher as a learning person, supported by the research team of a broader project about PCK (figure 1).

Moreover, in the vast field of psychological theory, several types of knowledge were described: factual, conceptual, procedural and metacognitive knowledge. We agree with Gunstone and Northfield [19] that understanding and controlling one's own learning are two fundamental metacognitive processes to promote teacher development.

Hence, in this research, we consider PCK as a complex knowledge that combines components from all of these types of knowledge in varied proportions and blendings. In addition, metacognitive knowledge [20], also labelled as metacognitive awareness, is truly important to develop personal PCK because it includes the knowledge of teaching strategies as well as the conditions to use them in an effective way, and the knowledge about one's own condition [21]. Consequently, our work aims to expose the processes through which a Physics teacher of secondary school level begins to rethink about his own practice, from the perspective of research in Science Education.

Although instructional labs in Physics can provide "hands-on" learning experiences from "cookbook" recipes, some new designs of instructional lab courses that include several cognitive task analyses are needed [22]. So, we wonder about the teacher's motivation to carry out a new practical activity for his students, his difficulties in planning it, his considerations when carrying it out and the knowledge that he builds along that process, we are taking into account the processes that are part of the development of the PCK of that teacher and the relevance of a particular context [23]. The way he has thought the practical activity design whether like a traditional one (highly structured) or an alternative lab proposal that allowing students to exercise greater autonomy [24], will show his conceptions and beliefs about nature of experimental Physics.

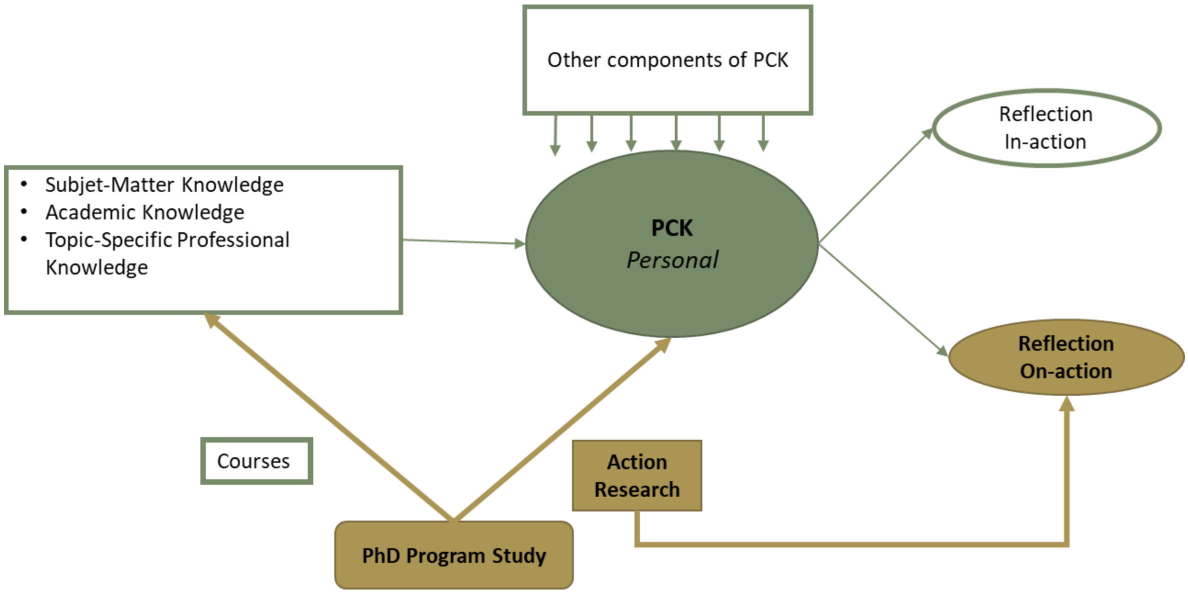

Figure 1. Key elements taken account in this work.

As of an experience carried out for the teaching of spectroscopy in secondary school level Physics lessons, from the construction of a homemade spectroscope, a reflection on the practice itself is proposed here to transform the teaching task into an object of investigation for the teacher. The processes involved in the selection of the topic, the basis for the design and implementation of the practical activity and the teacher's observations are described. For the design of the pedagogical proposal, two complementary aspects were taken into account. On the one hand, the role of practical laboratory activities for the teaching and learning of Physics [25]; and on the other, the need to incorporate new technologies such as the use of mobile devices as tools in experimental Physics lessons [26]. The wide selected topic was *the light* (Optical Physics) because it is a very well-known physical phenomenon and it admits a broad diversity of teaching proposals.

We accept that the experience of participating as a science education research project modified the personal PCK of a secondary Physics teacher, so, our specific objectives were:

- To describe the process (or pathways) of transforming a teacher into a research of his own practices;
- To detect his beliefs and orientations to teaching a particular topic of Physics;
- To promote the reflection-on-action (metacognitive knowledge) as a way to develop critical thinking and investigations skills.

2. Methodology

This study is part of a broader project "Science education research as a tool for improving science teaching and learning in Argentina", where PCK studies were included. It was initially based on the content representation (CoRe) instrument designed by Loughran and his team [27] because it is a holistic reflective tool to make knowledge and conception about a particular topic explicit [28]. Nonetheless, it was used in a different approach. Instead of being applied in groups of teachers to answer the questions, it was responded by only one teacher as part of an introspective and reflective act. So, in this way, CoRe is not part of topic-specific professional knowledge (TSPK) in the Gess-Newsome model [7], but it could be described as personal PCK because it refers to individual knowledge and experiences. Besides, in a second step, initial questions were reinforced with new ones (subsequent questions) in order to reach a broader spread of answers (table 1). In this case, the CoRe instrument was converted in a script for thinking in the framework of an action research [29,30]. At last, some metacognitive questions were included in order to capture the reflection about both the lesson and the self-experience.

Table 1. Initial and subsequent questions for the analysis of own practice (on-action).

Initial questions	Subsequent questions
How did you plan this particular lesson?	Why did you choose to work with the building of a homemade spectroscope?
	What do you mean when you say that: "Physics is taught in a *book way* or *too theoretical*"?
	How are your lessons?
Why do you believe that this topic is important for your students?	What do you mean when you say that: "Physics glance of the students"?
	Which are the learnings you expect your students to achieve with this experience?
	Could you give us any example about "critical and reflective thinking" in this case?
How did you design the activity?	Which sources did you use to plan the activity? How did you get them? How did you start to think about the activity?
	What do you refer as the student "being part of the teaching"?
	What did you want to share with your students?
	What aspects did you take into account in order to plan the activity?
Did you learn anything else while you were designing the activity which you didn´t include in the lesson?	Did any unexpected difficulty appear during the lesson?
Which manner do you expect your students to react to the proposed activity?	Were your expectations accomplished?
Which were your teaching strategies in this lesson? Why did you choose them?	Could you enlarge your response, please?
How do you realize if your students understood the topic	What do you do if your students do not understand the topic?
How do you assess your students' learning?	If you had to repeat the experience with a new group of students, would you do any change? Which one? Why?
	If another Physics teacher wanted to replicate your experience with his/her own group of students, which advices would you say him/her?

Implementation: As part of his Ph.D. program, Andy, a Physics teacher with six years of teaching experience, joined our research group of PCK in order to start an action research about his own practice. Thus, corpus of data was collected in the interaction between researchers and the teacher through an action-research strategy [31]. Communication was performed using virtual (WhatsApp & Skype), and personal meetings.

Context and participants of the research: The participants were five boys and girls of around 17 years old of a public secondary school of a small village of Argentine, it is located at 55 km of the university, where Andy is participating as novel researcher (figure 2).

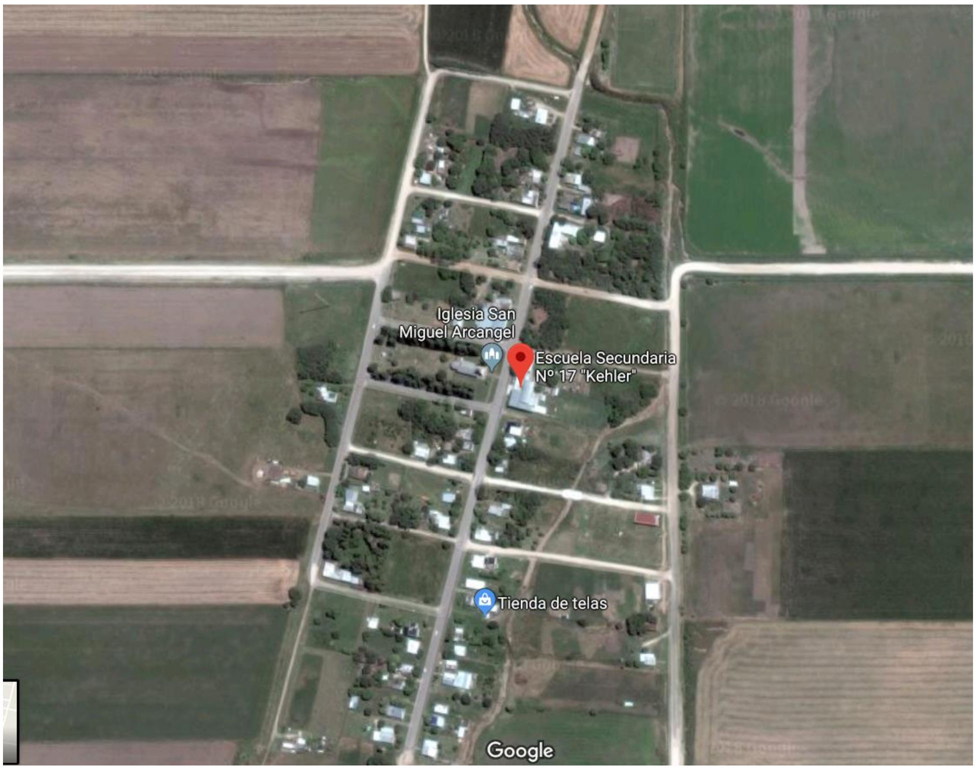

***Figure 2**. Location of the School Kehler N°17 in Aldea Salto, Entre Ríos, Argentina (https://maps.google.com).*

Students took part of a new practical activity specially designed by Andy to teach the topic, scattering of light, that belongs to the course of Physics II corresponding to the last year of compulsory secondary school, and the class was entitled as "Building of a handmade spectroscope" [32]. It was designed taking into account the elements exposed on figure 3. The required materials were: Black cardboard, scissors, glue, CD/DVD, photo camera or smartphone, printed previous reference images and the model of the spectroscope. The whole activity had a duration of around 70 minutes and was done in a morning class.

The activity was presented with the following instructions for students:

- Cut the cardboard according to the model gave by your teacher;
- Bend and assembles with glue to obtain the spectroscope;
- Do a little cut in the frontal part to allow the sunlight can go through it;
- Put the CD/DVD into that cut so the sunlight impacts on it. Then close the spectroscope;
- Get the frontal-cut closer the sunlight;
- Put the photo camera/smartphone in the upper part to record the spectrum of the light;
- Compare the picture with the reference ones.

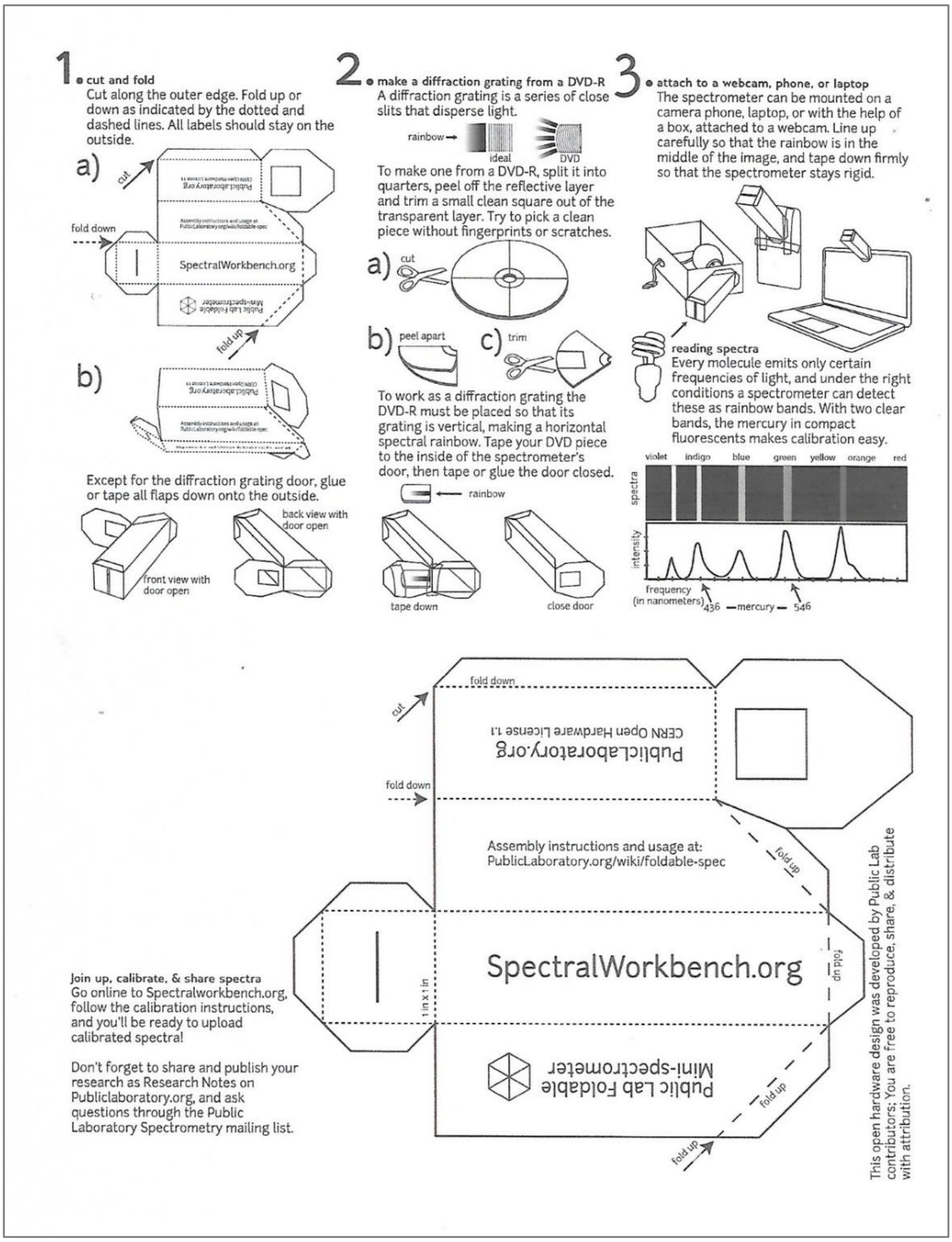

Figure 3. Model of handmade spectroscope (*https://publiclab.org/wiki/foldable-spec*).

The object of study was constituted by the enacting of the innovative class, the report of that experience and the written responses to all the questions previously mentioned.

Then, Andy registered his ideas and thoughts at the beginning of the course (February-April 2018). The purpose of this was to promote the self-reflection about the involved processes during the creation and planning of his lesson. At the middle of the course (June 2018), after the lesson was implemented, a new set of metacognitive questions were presented to Andy in order to encourage the reflection-on-action after the lesson and to develop his metaknowledge.

In this first and exploratory approach, a qualitative methodology was employed in order to detect plausible categories for further analysis.

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3. Results & Discussion

It is important to realise that the answers to the different steps of the questionnaire could reveal only the declarative knowledge of the teacher and, therefore, just the ideas and beliefs which he was able to make explicit. He valued the experimental nature of Physics, he also highlighted his role as a guide of his students during the experiments and the importance of the activity design according to students.

Although his design of the activities was based on the subject-matter framework, Andy showed a big interest to improve his lessons according to his students' motivations and their socio-economical context. He wrote:

"*The first thing I thought about was to look for something that was easy to do by any student, and that it was cheap. Besides, I thought about some ways to include ICT (smartphones and tablets) to catch pictures and save as a record*." **[*]**

"*Then, I searched bibliographic information in several of books such as Sears & Zemansky, and then I searched ideas from Internet and in works or papers about the topic using Google Scholar*".

He gave a starring role to his pupils in the lab. When he wrote about the purpose of using the construct of homemade spectroscope, in order to allow the kids to have "*the personal experience in the construction, and data collection in a fully experimental situation*" because it is important "*that they learn to observe the natural world and to analyze it at the same time they are discovering and interacting with it. In which way? Doing experiments*"

He also showed his knowledge and passion for teaching Physics and diverse ways to assess the students' understandings. He mentioned the following indicators that help students' learning evaluation: The way that students take notes; understanding level, abstraction level and type of selected ideas by students; oral and written expression; stated questions about the contents; activities of self-reflection of the students; and, new information about the topic supplied by students.

In the same way, he was capable of expliciting his subject-matter knowledge giving topic-specific examples as when he compared different types of bulbs of light (old-one and led-one) and their impact on the room temperature. Another aspect that is significant to mention is the importance given by Andy to the errors in experimentation as a way of constructing new knowledge.

However, his answers exposed some difficulties when explaining the rationale of the innovation and some inconsistencies between the teaching proposal and learning expectations. In the same way he was able to reflect about his technical new learnings, but not about other wider thoughts and knowledge carried out throughout the completed process.

When he had to answer about possible modifications to this particular lesson in the event of having to repeat the experience with a new group of students, he stated:

"*I would add some theoretical and procedural questions* (to the students) *about the experience to solve problems about the observed* (in the practical activity)." "*In addition to the report of the experience, I would ask* (to authorities) *that this topic was included in a Science Fair in order to allow students to participate in the scientific communication process]*.

When Andy thought about some advice for someone else who wanted to teach the lesson, he focussed on the necessity to extend at least in three classes, the number of lessons to carry out the experience. The first meeting could be to introduce the idea and to build the spectroscope. The second class could consist of taking pictures of different sources of light and then to compare their spectrums; and finally, the third one could be to assess the students' learning.

Two months later after finishing the whole activity, Andy had the opportunity to reflect about his own-process of teaching and learning, throughout the action research experience. When he faced the question about his feelings during the process of action research of his practice, he expressed:

... this experience *"opened my mind to rethink about my lessons. It is always necessary to search the way to apply the theory with experiments; and, to carry a complete record of the outcomes to* *reach a self-evaluation to improve the lessons. It is like putting oneself in the researchers' shoes and knowing that one can do an action research with the intention to improve* (the educative practices), *without missing the attention on the group* (of students)"...

When he was asked about his PhD studies, he stated:

"PhD study is a wide world. New ideas are always outflowing (from my mind) *and it is hard for me to keep focused* (…) *Sometimes, it seems like someone wishing to do everything, but at the same time, doing nothing."*

4. Conclusions

PCK model suggests that Andy's knowledge was modified and enriched with new strategies for searching information, for designing innovative practices and, mainly, in order to transform personal experience in an object to be analysed. Succession of questions and answers, and the participation of Andy in the research team, offered him the opportunity to revisit his experience including new analytical tools. These results are according to Viennot and Décamp work [33] who have suggested the utility that the science education research has to improve the development of both professional teaching and critical thinking of Physics teachers.

Our results are a positive contribution to consider PCK model as an appropriate research strategy to study teacher professional knowledge as well as to review and to reflect about the own teaching practices in the framework of an action-research perspective.

Though becoming a science education researcher is a long and complex process that needs the supports of others (pairs, mentors), our results have also shown the influence that the teacher intentions and knowledge has on the PCK development by means of searching for the best way to design the class for particular students in a particular context. In this sense, the PCK is enriched by the action research of a singular teacher's teaching pedagogical practice [34], who is worried about his students' interests and motivation and, at the same time, he enquires and reflects about his personal experience.

To go deeper into these pathways of changes and transformations, new experiences have to be studied from its design till its assessment. So, in the short term, new proposal for teaching Physics classes and reflections on it, should be regarded as a successful impact of the process to become a Physics education researcher. In the middle term, we would also expect a better and more complex argumentation and foundations of his proposals, and it should be considered as indicators of PCK enrichment.

In this way, our outcomes begin to lighten the *shadows* on the needed knowledge and process to become into a science education researcher.

Note: **[*]** Translation is our, and was discussed between research members, Andy, and an English expert.

5. Acknowledgements

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