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Research based activities in teacher professional development on optics

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Summary. — The aim of this research is to understand how teachers take ownership of content given them in formative intervention modules and transform it into suggestions and materials for teaching. To this end a module on optics was designed for a group of kindergarten, primary and lower secondary school teachers which sought to integrate meta-cultural, experiential and situated approaches with various context specific factors. The study investigated how teachers deal with conceptual difficulties in the module and how they adapt it to their school situations with data being gathered through a variety of tools. It emerged that the most difficult concepts teachers encountered at the formative stage were those they most often incorporated into their materials. The steps taken in this process of appropriation were then reviewed via a collaborative discussion among the teachers themselves on the materials they had produced.

1. – Introduction

The knowledge society and its rapid change have led to the need for new professionals and it is the teacher who perhaps has to change the most (Duffee, Aikenhead 1992; van Driel, Beijaard, Verloop 2001; Guskey 2002; Berger, Eylon, Bagno 2008). A wide research literature indicates that education based on resources and the transmission of content (the banking model) is not sufficient even when it promotes active student learning (Borko 2004; Gess-Newsome 1999; Oakes *et al.* 2000; Michelini 2004; Viennot *et al.* 2005). Education thus needs to take into account differences between trainee teachers (Lieberman, Wood 2001; Siskin 1994), and what they individually learn (Klein 2007; Lampert, Ball 1999) so that communities of professionals who ground learning in practice both as regards content (Ball, Cohen 1999; McLaughlin, Talbert 2006) and context

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(van Driel *et al.* 2001; Guskey 2002; Klein 2007) can be created. It is argued that with the help of professional teacher development teachers can become personally involved in specific contexts to transform those competencies that are most resistant to change (Klein 2007; Wayne *et al.* 2008; Borko 2004), especially as in any didactic innovation there tends to be a relapse phase that results in the reproduction of school practice, styles and traditional methods (TIMSS 2007; Angell 2012).

The focus in previous research has been on how professional development helps teachers to adapt their teaching practice so that their children can take an active role in the construction of knowledge and on how teachers transform the subject matter they are given in formative modules into suggestions and materials for teaching. In primary school the preparation of teachers in science raises a serious issue concerning subject content and the way such content can be taught to children in the form of games and ludic exploration based on conceptual challenge (Davis, Smithey 2009; Metz 2009; Mikeska *et al.* 2009; Michelini, Stefanel 2014). Thus, in the present research project a Formative Intervention Module (FIM, henceforth) on optics was designed for three groups of kindergarten, primary and lower secondary school teachers. Here we discuss the characteristics of the FIM, the way teachers face the conceptual problems on optics in the module and how they appropriated the concepts for use in the classroom.

2. – The formative intervention module - FIM

To help teachers improve their professional competence in the basic concepts of geometrical optics, design education activities to practice such concepts, assist their students in dealing with the conceptual challenges and learning difficulties involved and finally become aware of their own learning path a specific FIM was implemented. This was conceived as a formative path characterized by close interaction between researchers and teachers and following a modular format in which each teacher was supported in designing their own activities and implementing them autonomously in the classroom. It was the result of a collaborative process involving special agreements between the University of Udine and institutions including different kindergarten, primary and middle schools in three little towns in the area around Udine, and developed within the framework of a national school/university project [1].

Collaboration took place between university researchers, school teachers and the principals of the institutions. The FIM was designed by university researchers, discussed with teachers in all three schools and divided into three specific activities conducted in parallel in the three schools in five sessions of three hours each by (usually) a pair of researchers working together. It sought to integrate meta-cultural, experiential and situated - context specific teacher education approaches (Michelini *et al.* 2013) and started with an introduction to the history of optical concepts so as to gauge how teachers engaged with the interpretative problems on the mechanism of vision, basic optical phenomena and the nature of light. These issues were then re-explored operatively by teachers through simple experiments and a test (CK-PCK test below), based on problem solving, designed to encourage reflection on both the specific conceptual difficulties that occurred, and

[1] The activity "Adopting Science and Art in Primary Schools" is a section of the project IDIFO promoted by the Research Unit in Physics Education of the University of Udine in collaboration with 20 Italian Universities, in the National Plan for Science Degrees of the Italian Ministry of Education, Research and Universities.

how they could be addressed in the classroom (Michelini, Stefanel 2014; Michelini *et al.* 2014).

The design and implementation of microteaching activities were interspersed with formative sessions, to ensure both the active role of teachers in the construction of their conceptual basis and to enable them to reutilize this experience as a method of inquiry with their own students. The steps suggested for teacher- student interaction were as follows:

Pupils

A) search autonomously for information (in the form of photos, pictures, etc.) from books, cartoons, newspapers that illustrate light phenomena;

B) decide how to classify their various information using their own criteria;

C) discuss with teacher a new classification according to criteria based on physics phenomena classification;

D) do experiments with simple apparatus in the classroom on the phenomena that have emerged;

E) explain the information they collected in A on the basis of the physics criteria discussed in C;

F) visit an online gallery and identify light phenomena in selected pictures;

Table I. – *Outline of the FIM on optics for primary school.*

Session – Content
I - Historical conceptions of light as evidenced in research on: optical phenomena; mechanism of vision • Reconstruction of the meanings of the concepts involved (through experiments): • Re-construction of what is involved in the mechanism of vision (properties of light, interaction light-object, role of light (reflection, diffusion, entrapment) • Rectilinear propagation of light and experimental evidence for it • Experiments to explore reflection, refraction • Shadow formation by sun-light (sun motion and the reference system) • Smoke chamber and the phenomena of light-matter interaction
II - Operative path on sun astronomy: direction of the sun's rays; illumination and the seasons
III - Experiment on refraction laws and image formation via a lens. Operative path on light and colors (interaction between light-object, light-eye)
IV - Conceptual problems in optics as background for educational design
V - Interplay between the educational direction taken in teacher formation and the process teachers implement in the classroom with their pupils.

G) individually produce their own picture of one or two phenomena, explaining it with a short text and uploading their work onto the web for "I-like" and quality jury evaluation.

3. – Goal of the present study and the research questions

The present study in the area of professional teacher development seeks to explore the process by which teachers take a particular educational direction, by focusing on the following research questions:

RQ1: how do teachers engage with the conceptual knots on light and the mechanism of vision explored in the MIF?

RQ2: how and how far do they adopt and use in classroom the historical premises, experiments and problem solving activities suggested in such sessions?

RQ3: how do they transform the educational path offered them in MIF?

4. – Monitoring instruments

The data on the process activated in the FIM were collected using a variety of different instruments and sources:

A) A researcher took written notes on the dynamics that developed in the training sessions, noting in particular how the teachers reacted to the suggestions made by the researcher in charge of the session, and what questions they posed during each session, and what their learning problems and suggestions were:

B) The teachers also made written notes, creating a personal record of what they felt they had learnt during the FIM and what was still unclear to them so that a general picture of what concepts were clear, what problems had been faced but overcome and what was still problematic could emerge from the sessions.

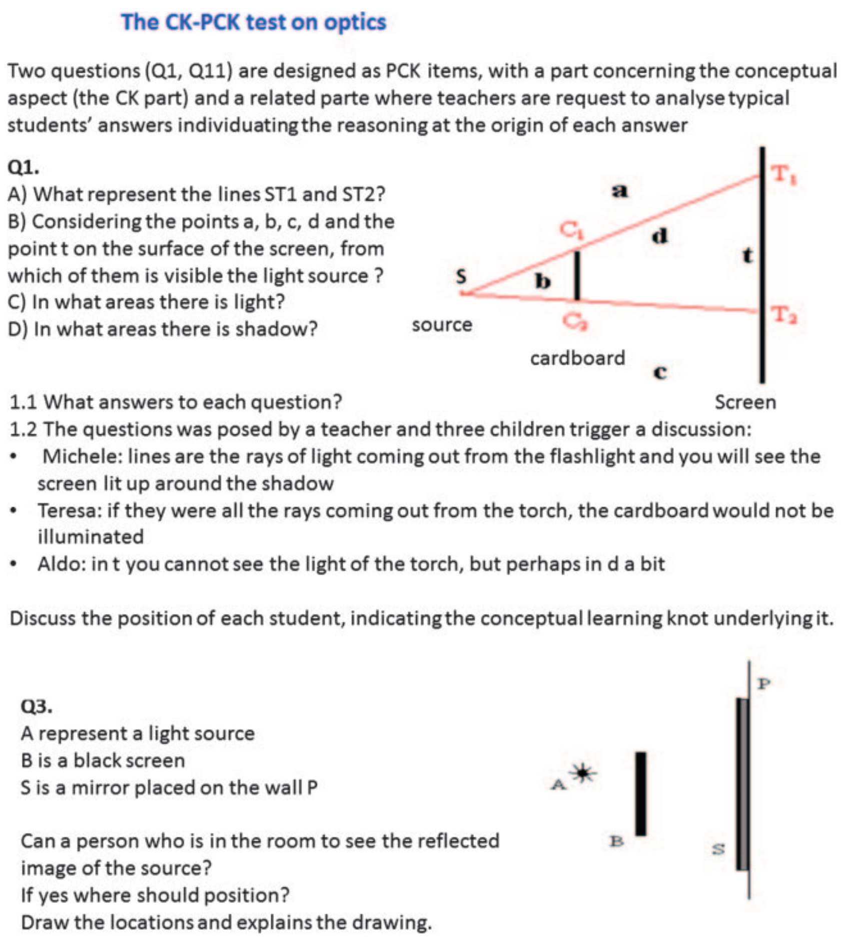
C) A test (the CK-PCK), described in fig. 1 below, was used to monitor learning problems. The teachers answered the questions at home both at the beginning of the FIM and after content sessions.

D) A series of microteaching tasks were developed by the teachers at the end of the module. These were tested out in class and analyzed to see how far they had modified the proposals made by the FIM. Finally, the further materials produced by their pupils was also analyzed to gauge how much such pupils had learnt from the process.

E) Learning outcomes of the teaching/learning process, as documented by the teachers, were used to gain indirect information on the educational direction taken, how the teachers worked in the classroom and how the pupils learnt.

Results and findings emerge by the triangulation and cross check of data.

A CK-PCK test was designed to address the main learning problems considered in the FIM. The test comprises 20 items (Q1-Q20), each of them concerning a specific conceptual knot: the mechanism of vision (Guense 1984, Galili 1996); the rectilinear behavior and the formation of shadow from a source point, from two source points, from a diffused source (Wosilait *et al.* 1998); reflected light travel (Bouwens 1987, Colin *et al.* 2002); how an image is formed with a flat mirror; the illumination of perfectly


The CK-PCK test on optics

Two questions (Q1, Q11) are designed as PCK items, with a part concerning the conceptual aspect (the CK part) and a related parte where teachers are request to analyse typical students' answers individuating the reasoning at the origin of each answer

Q1.
A) What represent the lines ST1 and ST2?
B) Considering the points a, b, c, d and the point t on the surface of the screen, from which of them is visible the light source ?
C) In what areas there is light?
D) In what areas there is shadow?

1.1 What answers to each question?
1.2 The questions was posed by a teacher and three children trigger a discussion:
- Michele: lines are the rays of light coming out from the flashlight and you will see the screen lit up around the shadow
- Teresa: if they were all the rays coming out from the torch, the cardboard would not be illuminated
- Aldo: in t you cannot see the light of the torch, but perhaps in d a bit

Discuss the position of each student, indicating the conceptual learning knot underlying it.

Q3.
A represent a light source
B is a black screen
S is a mirror placed on the wall P

Can a person who is in the room to see the reflected image of the source?
If yes where should position?
Draw the locations and explains the drawing.

Fig. 1. – The PCK question Q1 and the CK question Q3 of the test.

reflecting walls in a room with a little bulb (Rone, Eylon 1993; Viennot 1996); the light pattern passing from one medium of propagation to another; how images are formed by refraction (Fredlund, Airey, Linder 2012); and image formation by means of a tin lens (Goldberg, McDermott 1987). Two questions are designed as PCK items, with one part concerning the contents and conceptual aspect (the CK part) and another part where teachers are requested to individuate reasoning behind typical student answers and suggest interventions modality. Here we consider the PCK question Q1, concerning the rectilinear propagation of light, and the CK Q3 question on reflection (fig. 1).

5. – Methodology of analysis

The analysis of the open responses in the CK-PCK test followed the criteria of qualitative research (Erikson 1998; Niedderer 1989) and sought to individuate qualitatively different typologies, or categories, of answers (Niedderer 1989; Stephanou 1999). To this end it set out to construct mutually exclusive profiles, by means of a phenomenographic methodology (Lieberman and Marton 1981). The categories of answers concerning CK questions were based on interpretative criteria (which elements of the scientific model were included, and how comprehensive or naïve the understanding shown was), descriptive criteria (which elements were focused on), trainee conceptions and learning problems. The categories of answers relating to PCK questions considered the ways the teachers suggested facing any learning problems in the classroom.

The data emerging from the CK-PCK test distributed at the beginning of the FIM were compared with the notes taken by the researcher/observer and with those written in free form by the teachers to highlight the issues they had understood and the areas that remained problematic.

The educational materials and procedures prepared by teachers were first subjected to a content analysis to identify the ideas they included and how they intended to implement them in the classroom. They were then given a project design analysis using instruments and criteria established in previous research (Borghi *et al.* 2004, Michelini *et al.* 2004, Bisesi, Michelini 2008). The educational paths outlined by teachers were evaluated on the basis of the elements listed below, assigning a point, from 0 (element absent) to 3 (excellent element):

A) Rationale of the path taken; B) Coherence/logic of the educational path taken; C) inclusion of experiments; D) Student centred approach; E) Discussion of the motivation for their choices.

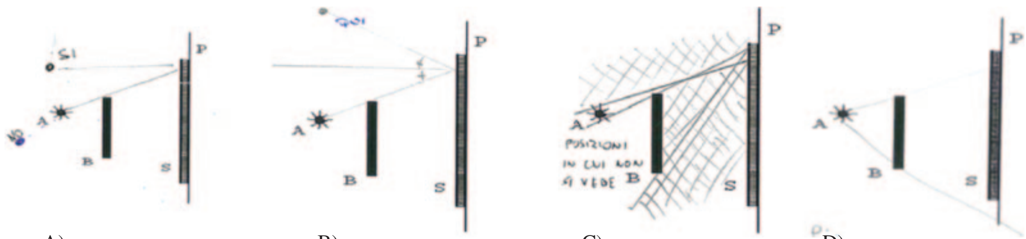
6. – Analysis of CK-PCK test (implemented during the FIM)

As far as trainee learning problems are concerned we can consider here the answers to question Q1 (from which point the light source can be seen; at which point there is light and in which shadow; and what comments were made on the children's responses) and Q3 (fig. 1), on rectilinear propagation and reflection.

With regard to the first two points of question Q1 there were quite different responses, although teachers would probably have expected the same answer (table II). The source is seen from: the areas ABC (13/18); only two zones (either AC or BC) (3718), only

Table II. – *Categories of answers of Q1 item.*

Question	Category A	Category B	Category C
A) What do the lines ST1 and ST2 represent?	Rays passing beyond the card (3/18)	Light beam/rays (9/18)	Limits of the light cone from the torch (6/18)
B) Considering points a, b, c, d and point t on the surface of the screen, from which of them is the light source visible?	abc (13/18)	ac or bc (3/18),	b (2/18)
C) In what areas is there light?	abc (8/18 – all 13) abc and partially in the region T1C1C2T2 "because light diffused" (2/18).	in b and along ST1 e ST2 (4/18)	≪on the screen≫ (2/18)
D) In what areas is there shadow?	in d and t (8/18)	in t (6/18) in d (2/18)	in acdt (2/18)



A) B) C) D)

Fig. 2. – Typical representation of the teachers concerning the points from where it is possible to see the image reflected by the mirror of the source.

the area B (2/18). It has light: in the areas ABC (8/18 - all of the 13 above), along ST1 and ST2 (4/18), on the screen (2/18) on ABC and partly in the region T1C1C2T2 "because the light spreads" (2/18). There is shadow in d and t (8/18), t (6/18); in d (2/18); in ACDt (2/18). As for the way the teachers analyzed student sentences (Michele: ≪lines ST1 and St2 are the rays emerging from the light source≫), it emerged that they essentially individuate those aspects they consider problematic for students: light propagates in a rectilinear way (11/18) and "S-t1 S-T2 are border rays" (3/11); Michele perceives light only at its limits (2/18); he describes the situation (2/18); "He tells the truth, identifying the illuminated area" (2/18); the cardboard prevents the rays from passing (1/18).

The difficulties encountered in the analysis of rectilinear propagation of light situations were then overcome at the end of the FIM by the teachers, who succeeded in transforming these situations and problematic questions into teaching activities.

As regards the reflection situation proposed in question Q3 (fig. 1), the typical representation of the teachers is shown in fig. 2, concerning the points from where it is possible to see the image of source A reflected by mirror S. The frequencies of occurrence are: A) 2/18; B) 8/18; C) 5/18; D) 2/18. A fifth category includes the assertion "behind the screen" (1/18). Although these teachers knew the law of reflection, they adopted alternative models to indicate areas from where the image of the source is visible. As can be seen, only in case B is there a local application of the law of reflection.

Considering the teacher home work "Analysis of the single items of the test", there were two main problem areas: how the image is formed by reflection emerged at an explicit level ("I am not clear how an image is formed by reflection"); and refraction emerged a problematic area at different levels (image formation, refraction law) and remained problematic. The items that they suggested teaching pupils were reflection presented in a symbolic form and refraction presented with photos of real situations.

In the teacher written work "what I learned during the FIM", it is possible to make the list of the subject matter of the MIF that constitute the explicit learning of teachers: A) Mechanism of vision; B) Rectilinear propagation; C) Color formation; D) Parallelism of sun rays; E) Ray deviation in refraction, while the consideration most widely shared was the conviction that they had changed their "way of teaching" and extended their "own safety zone" in dealing in the classroom with themes in the field of optics.

This change effectively emerged also from the analysis of the educational project designed by the teachers. The themes of the educational paths designed by $N = 15$ teachers are summarized in table III, for each of the three teacher groups: kindergarten, primary, middle school.

Table III. – *The content included in the educational paths. Ki: teacher of kindergarden; Pi. teacher of primary school; Mi: middle school teacher. The numbers indicate the sequence designed.*

Teacher	Different processes of interaction light-matter	Rectilinear propagation	To see the light	Light sources	Vision mechanism	Reflection as phenomenon	Reflection law (inc angle = refl angle)	Formation and symmetry of the reflected image	Diffused reflection	Refraction as phenomenon	Imagine viaa lens	Absorption phenomenon	Shadow formation	Sun as a light source	Colors	Dispersion
K1	1	3			2	4		5								
K2	1	3			2	4				5						
K3	1	3			2	4				5						
K4	2	4			1	5		6		9			3		7	8
P1	5	4	1	2	1	7	8	9		10			6	3		
P2		1				3				4			2			
P3		1				3				4			2			
P4	1	2				3	4			5	6					
P5	1	6	5	2	3	7		8		9			4			
P6		2		1		4		5		6			3			
P7		4	3	2	1	6	7	8	9	10			5			
P8	5	4	3	2	1	9	10		7	11		6	8			
M1		1	2			3				4					5	
M2		2			1	3	4			5	6				7	
M3		1				2			3						4	
Tot	8	15	5	5	9	15	5	6	3	13	3	1	8	1	4	1

In the following we discuss how teachers appropriated content and transformed it into teaching plans. Among the issues that took up most time in the FIM both in terms of the situations discussed and the experiments carried out, all or almost all of the teachers identified the rectilinear propagation of light and the recognition of reflection and refraction phenomena as core nuclei to be presented to the students. The approach adopted by the teachers for their students was most often limited to the recognition of the phenomenon and only 1/3 of them included the law underlying the phenomenon of reflection, how it is possible to "see" light (for instance using a smoke chamber), and how shadows are formed. 2/3 of the teachers explicitly included the physical mechanism of vision in their educational project in line with the emphasis given to it during the FIM as a prerequisite for an approach to the phenomena of light. For the remaining 1/3 of

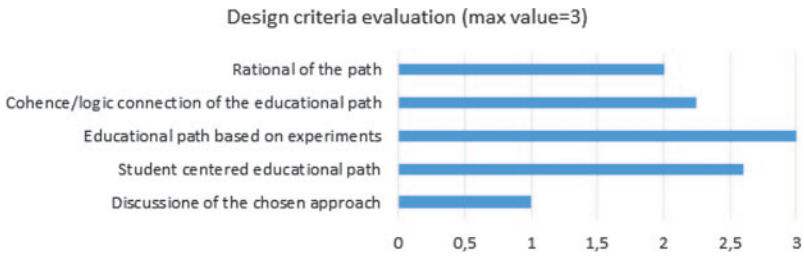


Fig. 3. – Evaluation of analysis criteria. For each project a point from 0 to 3 is assigned to each criterion. The mean valueas assigned to each criteria in the 25 projects are reported in the diagram.

the teachers this aspect remained at an implicit level or was completely neglected.

Individual aspects, such as image formation in a lenses, or absorption, were included as issues to be dealt with by only a few teachers, while the colour of objects was a topic touched upon by all the middle school teachers. The study of the sources, usually classified into primary and secondary sources, as is often done in textbooks, was included by 1/3 of teachers, although it was barely mentioned in the FIM.

The conceptual difficulties that emerged as problematic during the formative sessions, such as those related to the formation of images by plane mirrors and the reconstruction of the path taken in the propagation of light in the case of refraction, were also those most taken into consideration in the teachers' plans.

The analysis of the educational paths proposed by the teachers on the basis of the design criteria is shown in fig. 3. This indicates that a general use of experiments, a student centered focus and ease of transferability in putting the paths into practice were important features. This was confirmed by the analysis of the pictures created by the pupils at the end of their learning path, where a major role was played by the experimental situation explored, the symmetry of the reflected image, the features of the refracted images and the use of simple apparatus that could easily be reproduced.

7. – Conclusion

The study presented here focused on the professional development of teachers. It looked at the process of appropriation by teachers of an educational path in optics. A Formative Intervention Module on optics was designed in a research collaboration between the University of Udine and some schools in the neighbourhood of the town of Udine. It was characterized by close interaction between researchers and teachers, had a modular nature, and integrated, in the activities and personal work of the teachers, meta-cultural, experiential and situated approaches. To collect data different instruments and sources were used, to extract information on the formative process from different points of view.

As regards the way teachers engaged with conceptual difficulties concerning light in their formative module (RQ1), it emerged from the data that they experienced the following areas as problematic: image formation by reflection (symmetry); shadow formation and rectilinear propagation of light. Only 1/3 of them chose the mechanism of vision, important for their overall understanding, as a learning goal. More than the laws of reflection, the teachers tended to focus on reflection/refraction as phenomena (where it is possible to recognize them) and on features of the reflected/refracted images. The conceptual problems that remained were also problematic in the teaching, as for instance how to explain an image in terms of the law of reflection, how to explain images in terms of the law of refraction, and how to choose examples to represent them (RQ1).

As regards the way and the extent to which teachers selected and used the historical premises, the experiments, the proposed problem solving (RQ2) in their classrooms, it emerged that crucial for their appropriation of the educational path explored in the formative module were experiments performed by themselves/constructed by themselves; the coherence of the conceptual path followed in the formative module; the problem solving activities and reflection; and the analysis of the questions of the CK-PCK test. Moreover, maximum attention was given, in the educational paths designed and implemented in the classroom by teachers, to creating an active role for the students and more in general to ensuring student learning. The concepts included were those that were clearer to the teachers such that problematic concepts in their personal formation remained unresolved in the teaching sequences. The historical premises in optics were retained by teachers as part of their personal culture, but did not appear to influence the content of the educational path designed and implemented in their classrooms. (RQ2)

As for the way teachers transformed the educational path outlined in their training (RQ3), a variety of content was selected: they tended to focus on the themes connected with the reflected image and its symmetrical properties while generally speaking they did not include diffused reflection or, as stated above, the mechanism of vision. They transferred their learning path into teaching sequences paying attention to pupils own learning activities activated by experimental exploration. (RQ3)

In conclusion what emerges from the study was the important role in the formative module, first, of a research based educational path as a point of reference for the design activities of the teachers and, secondly, the hands on activities they experienced that helped them to understand how to teach very young pupils important concepts, how to reflect on conceptual difficulties to clarify the concepts and how to face such problems with their students in the classroom.

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