Professional Development Through the Use of Learning study: contributions to pedagogical content knowledge in biology

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Abstract

The aim of this paper is to describe a professional development approach—learning study—in which teachers and researchers iteratively and in collaboration develop a teaching strategy for students in upper secondary school to scaffold students’ learning of the relationships between genes and traits. Three research lessons were planned, conducted, and assessed, with an successive and significant increase in the students’ learning outcomes. The growth in teachers’ pedagogical content knowledge was evident from their improved awareness of which aspects of the content were critical to learning and thus should be varied during instruction.

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1. Introduction

In biology education, the topic of genetics and especially the links between genes and observable traits have been demanding for students to learn (Duncan & Reiser, 2007; Hickey & Zuiker, 2012; Lewis & Kattmann, 2004). Understanding the relationships between genes and traits is an example of the knowledge base that underpins genetic literacy (Bowling et al, 2008), which is the sufficient knowledge “to allow informed decision-making for personal well-being and effective participation in social decisions on genetic issues” (p. 16). Genetic literacy may be seen as a component or subset of scientific literacy (Laugksch, 2003; Roberts, 2011), which is a concept well established in most countries’ curricula (Dillon, 2009), and exemplified in the 21st Century Science project in England (Ratcliffe & Millar, 2009) as well as new curricula in Turkey (Canziz & Turker, 2011) and the Netherlands (van der Valk & Eijkelhof, 2007). The study reported in this paper was conducted in Sweden, where the science curriculum states that the aim of biology education at the upper secondary level is to provide “such knowledge as stimulates active participation in public discussions of social matters that require a biological perspective” (National Agency of Education, Biology, p. 27, authors’ translation), thus well in line with the idea of scientific literacy and education as tools for citizenship.

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This study was designed as action research, using a variation of lesson study (Hiebart & Stiegler, 1999; Lewis, Perry & Murata, 2006) known as learning study (Holmqvist, 2011; Mun Ling & Marton, 2011). The difference between lesson study and learning study lies in the latter’s inclusion of a theoretical framework about learning in general. Learning study, like lesson study, is an iterative process in which teachers and researchers jointly plan and conduct lesson designs, using the assessed learning outcomes of the first lesson as the basis for adjusting the design of the next lesson to present the content more effectively. Three or more lessons on the same specific content are implemented in different groups of students, making it possible through differences between the pre- and post-test results in each group, to analyze how the different designs affect learning outcomes. During the process, the teachers also study the actual content (content knowledge), the principles of a theoretical framework of learning (pedagogical knowledge), and research into science (in this case biology) education (pedagogical content knowledge) (Berry, Loughran & van Driel, 2008; Schulman, 1986).

The aim of this paper is to describe this professional development approach (learning study) that iteratively develops a teaching strategy for upper secondary school to scaffold students’ efforts relate single scientific concepts and coherent scientific explanations. In this case, the topic used to exemplify such relationships was genetics and the specified object of learning was the relationship between genes and traits. Teachers worked with researchers to design three research lessons in which the results of the first informed the development of the second, and results of the first two informed the development of the third. The specific research questions, below, concerned the teachers’ own professional development during the design and implementation of these teaching strategies.

- In what way(s) is the participating teachers’ pedagogical content knowledge developed?
- In what way(s) is the participating teachers’ development related to the students’ learning outcomes?
- In what way(s) is the participating teachers’ development carried into action through changes in lesson designs?

2. Background

Because genetics seems to be one of the most difficult topics in science education (Duncan, Rogat, & Yarden, 2009; Hickey & Zuiker, 2012; Tsui & Treagust, 2010), it is of particular interest to identify those aspects of it critical to students’ learning. Knowledge in biology is structured around different organizational levels, and those particularly important in genetics are, according to Knippels (2002), population, organism, cell, gene, and molecule. There is confusion among students about definitions of single concepts (Allchin, 2000; Lewis, Leach & Wood-Robinson, 2000), for example the distinctions between genes and chromosomes and between somatic and germ cells. Explaining the relationship between genes and traits requires process thinking, includes an enormous amount of variation, and often focuses on parts rather than the whole (Duncan & Reiser, 2007; Marbach-Ad, 2001).

To study why this topic is so difficult to teach requires consideration of a number of its aspects from different perspectives. The sociocultural perspective emphasizes the culture of science, with its particular forms of language, reasoning, and representations for shaping learning. Lemke (2001) holds that some features of language used in biology education, including words (e.g. gene/allele), grammar (e.g. nominalizations), and thematic patterns (e.g. parts vs. wholes, and organizational levels), have a great impact on how the content is understood. One aspect of Vygotsky’s (1978) socio-historical perspective concerns the mediated learning of cultural tools in formal settings. In genetics, these tools are not often physical and concrete, instead they are symbolic and abstract. Kozulin (2003) points out that symbolic tools are situated and “derive their meaning only from the cultural conventions that engendered them” (p. 26). Furthermore, Kozulin emphasises that appropriation of symbolic tools is ineffective if there is no human mediator present, which highlights the importance of teachers’ communication strategies.

Although communication strategies are important, however, the best communication strategy is futile without something to communicate—the content. In variation theory (Marton & Tsui, 2004), in which learning is seen as the development of a new and more nuanced way of discerning a phenomenon, such content is analyzed at the micro-level. This is accomplished by varying which aspects of the object of learning are brought into focus, while others remain in the background. The real challenge for the teacher is to identify the aspects that are critical for understanding the object of learning in a more developed way, which are those not yet discerned by the learner(s).
The focus in this study of professional development was on the content and how it was handled more and more precisely by the teachers to meet the students’ needs. When describing features of professional development and increased teacher knowledge, Schulman (1986) introduced the idea that different types of knowledge might contribute to a professional teacher’s knowledge base. Current discussion often focuses on three types of teachers’ knowledge—content knowledge, pedagogical knowledge, and pedagogical content knowledge (Archambault & Crippen, 2009; Wallace & Loughran, 2012). Our assumption is that these three are intertwined in a learning study, and that pedagogical content knowledge may be specified in biology education as suggested by Park and Chen (2012, p. 1), that pedagogical content knowledge consists of five components: (a) orientations toward teaching science, (b) knowledge of student understanding, (c) knowledge of instructional strategies and representations, (d) knowledge of science curriculum, and (e) knowledge of assessment of science learning.

3. Research design and methodology

3.1. Participants

This intervention study in a Swedish upper secondary school involved two science teachers, two educational researchers, and 27 students from two classes, randomly mixed into three research groups. The teachers were formally qualified to teach biology to that particular age group and had approximately five and ten years of teaching experience respectively. The students were 17 to 18 years old and had passed Biology A, a course that covered “the relative importance of heredity and environmental factors in relation to individual characteristics” (National Agency of Education, Biology A, p. 28, authors’ translation), which was the content investigated in this study. The two teachers assumed and feared that students’ learning outcome during the course was mainly limited to single facts, instead of including an understanding of the process. For that reason, the teachers wanted to investigate which critical aspects of the topic would help the students understand the genetic principles taught in Biology A. The 27 students were formed into three new groups (A, B, & C, see Table 1) for the research lessons. Each research lesson lasted approximately one hour, including pre-and post-test.

| Table 1. Participating students by lesson and gender |
|---------------------------------------------------|
| Research lesson A (n = 9) | Research lesson B (n = 10) | Research lesson C (n = 8) |
|---|---|---|
| Girls | 3 | 6 | 4 |
| Boys | 6 | 4 | 4 |

3.2. Methodology

Prior to teaching the 27 students in the intervention, the teachers gave a written screening test of content knowledge to a comparable group of students (N=33) of the same age who had completed Biology A. The results of that screening formed the basis for planning the teaching intervention, especially research lesson A, and for the design of the pre- and post-tests. The teaching intervention consisted of three different research lessons (A, B, and C), which were each taught to a new randomized student group and videotaped. Each group of students was tested before and after the research lesson, and the results of the previous research lesson were the basis for improvements in the lesson to be taught in a new group of students. The same teacher taught all three-research lessons, not only to minimize the effect of different teachers’ personalities or teaching styles, but also to make it possible to follow changes in the same teacher’s way of teaching over the whole study. Students were tested three weeks after the intervention (delayed post-test) to estimate their long-term retention of learning. The timeline is shown in Table 2.
3.3. Analysis of screening, test questions, and research lessons

In face-to-face meetings, the teachers and researchers discussed and assessed the students’ answers on the screening and pre-, post-, and delayed post-tests. Because the same group assessed all three interventions and all tests, the assessments and scores could be compared across groups. The researchers conducted a pre-meeting qualitative analysis of the video of the enacted lessons before discussing the enactment of the planned teaching strategy with the teachers (see 4, 11 & 18 March in Table 2).

The five questions in the screening test answered individually and in writing were: 1. What are genes? 2. What is a genome? 3. What is DNA? 4. What are chromosomes? 5. How do these elements relate to each other? The answers were grouped into qualitative categories indicative of the students’ reasoning.

In the pre-, post-, and delayed post-tests, each student was asked to “use the terms DNA, chromosome, genome, and gene to explain how kittens born at the same time to the same parents can all have different fur colors.” Qualitative analysis revealed aspects critical to understanding the process of genetic expression. After the teachers agreed upon which aspects should be included in the understanding of the relationship between genes and traits, these aspects were scored, resulting in a 10-point scale used along with the qualitative analysis of the videotaped lesson of how the object of learning (the relationship between genes and traits) was handled during the lesson. The ten scored aspects were recognition of: the genome as an equal combination of DNA from the egg and the sperm; the genome as the physical substance transferred to the offspring; the DNA molecule as a chromosome; the contribution of many different genes to each DNA molecule; the contribution from each parent of half of the offspring’s chromosomes; the temporary condition of chromosomes; the dominant, recessive, or intermediate modes of alleles; the significance of genes in protein production; the influence of different gene and the influence of the environment.

4. Results

In this section we will present first the quantitative results of the screening (the pre-, post- and delayed post-tests) and second a qualitative analysis of the teaching strategy in the research lessons.

In the screening a sample of 33 students were asked five questions, the first four of which asked for definitions of the concepts gene, DNA, genome, and chromosome and the fifth asking how these concepts relate to each other. The students gave fairly sound definitions in the first four questions, indicating good understanding of four basic concepts; however, 31 out of 33 students failed to describe adequately how those basic concepts are related to each other, indicating their only vague understanding of the learning object in this study—the various causes of individual traits.

The only question used in the pre-, post- and delayed post-tests was, “Use the terms DNA, chromosome, genome, and gene to explain how kittens born at the same time to the same parents can all have different fur colors.” The
students answered a pre-test (A1, B1, C1) at the beginning of each research lesson and were asked the same question as a post-test (A2, B2, C2) at the end of each lesson, allowing us to analyze differences in their knowledge just before and just after the research lesson. The same question was given as a delayed post-test (A3, B3, C3) three weeks after the research lesson to study the long-term outcome. Because the students in the three groups returned to their usual classes after the research lessons, they had the same conditions before and after the research lessons. The mean scores and ranges are summarized in Table 3; Table 4 shows the results of a paired t-test.

### Table 3. Mean scores and range (0–10) in tests

|                        | Research lesson A | Research lesson B | Research lesson C |
|------------------------|-------------------|-------------------|-------------------|
|                        | Mean   | Range | Mean   | Range | Mean   | Range |
| Pre test               | 3.11   | 1–6   | 3.30   | 0–6   | 2.75   | 1–5   |
| Post test              | 3.22   | 1–5   | 4.10   | 2–6   | 5.00   | 3–8   |
| Delayed post test      | 3.44   | 1–6   | 3.50   | 1–6   | 4.50   | 3–7   |

Table 3 (mean score) and Table 4 (t-test) indicate an increase between pre-and post-test in all research lessons, smallest in research lesson A, but successively larger in lessons B and C. Analysis at an individual level (following each student’s result) showed that in the first research lesson (A), 3 of the 9 students (33%) improved their results from pre- to post-test. In the second lesson (B), 7 of the 10 students (70%) improved their results, and in the third lesson (C), 6 of the 8 students (75%) improved their results.

### Table 4. Paired t-test, sig 2-tailed (from SPSS 20.0)

| Pair     | A2/A1 | A3/A1 | A3/A2 | B2/B1 | B3/B1 | B3/B2 | C2/C1 | C3/C1 | C3/C2 |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| t-value  | 0.426 | 0.816 | 0.800 | 1.395 | 0.318 | −0.896| 2.393 | 1.986 | −0.734|
| p-value  | 0.681 | 0.438 | 0.447 | 0.196 | 0.758 | 0.394 | 0.048 | 0.087 | 0.487 |

As shown in Table 4 there were no significant differences between test scores in research lessons A and B. However, in research lesson C there are significant differences, the difference in test scores was 2.39(p=0.048; 0.05-level**) between pre- and post-test, and the difference between pre- and delayed post-test was 1.99(p=0.087; 0.1-level*), indicating sustainability of the developed knowledge.

The quantitative results showed gradually improved learning outcomes in the three groups; a qualitative analysis was conducted of the videotaped teaching strategy and classroom interaction in each research lesson. Each videotaped research lesson lasted approximately one hour, including pre-and post-test.

The first research lesson started with a peer-group discussion about reasons for different hair color among the members in the group. The second part of the lesson was a teacher-led discussion of the origin of the trait PKU (phenylketonuria) in newborn babies that results from a mutation in the DNA. Thus, two traits (hair color and phenylketonuria) and their origins (natural selection and mutation) were used to provide variation in aspects of the object of learning. During the analysis, however, teachers found the example using PKU confusing because its origin in mutation changed the focus in the classroom from the general process of genetic expression to one distracting detail. The students’ answers in that class attribute all differences in any trait to mutation, which in turn
led the teacher to focus on that process rather than its status as a variant of the general rules of genetic inheritance. Presenting various aspects at both micro and molecular levels at different stages in the process was also found to be an obstacle for the students. The teachers’ analysis of the video focused on low learning outcomes and how they could be changed through a different focus in teaching.

The second lesson started with a video clip showing two newborn twins with different skin colors, followed by a peer-group discussion about possible reasons for this different skin color. The video was supposed to illustrate the relationship between genes and traits; it showed two parents (both with light skin) who had twins with different skin colors (one darker and one lighter). The second part of the lesson was a teacher-led discussion of how three different genes affect three different traits; during this discussion the teacher drew an illustration on the blackboard showing this complexity. Complexity (variation) was shown to increase as more traits and genes were introduced, and it was only the origin of traits through mutation that was invariant in this lesson. The learning outcomes in this lesson were higher than in the first, and the teachers found that the differences in the design improved the students’ abilities to learn the content. However, more aspects needed to be developed, for example the effect of environmental factors on expressed traits and in what stage of the process such effect can occur. In the latter part of the enacted lesson, the teacher lost focus on the specific trait (skin color) and discussed variation of other traits, which led to some confusion at the end of the lesson. In this case the teachers and researchers decided to keep the first part of the lesson design, but to change the rest.

Thus, the third lesson started the same way as the second, using the same video clip and peer-group discussion. The second part of this lesson was a teacher-led discussion focused on how different alleles affect specific traits (in this case, skin color) using the example from the video. The students were thus able to focus on the process instead of the varying traits. Variation theory holds that the aspect focused upon in the lesson should vary against an invariant background of other aspects. During this discussion the teacher drew an illustration (see Appendix 1) on the blackboard showing the genetic pathway from parents to children. While drawing this, the teacher explicitly showed the macro level (phenotypes of parents and babies) and micro/molecular level (alleles of genes) of the different levels of biological organization. In the demonstration of the macro level, only skin color varied; for the micro level, only the alleles varied. The two levels of organization were used in parallel during the whole lesson, thus illustrating the relationship between parts and the whole. The influence of the environment was also discernible in both the prenatal (micro/allele) and after birth (macro/phenotype) phases.

During the learning study, the teachers developed their knowledge in the field by questioning their own presumed knowledge about genetics. Because the teachers had to focus on what exactly the students did not know, the teachers had to ensure that they themselves were confident in that knowledge and able to articulate it precisely through instruction and interaction with the students. The teachers’ growing knowledge of how to vary and focus the aspects needed to teach the particular object of learning and to keep the unfocussed aspects invariant was shown to affect both their design of the instruction and the students’ learning outcomes in the amended lessons.

5. Discussion

The results of the screening underlined a recurrent dilemma in science education, namely that students seem to learn single concepts but are not always able to combine them in thematic patterns—to connect the parts in order to tell a coherent scientific story (Brown & Ryoo, 2008; Lemke, 2001). The object of learning in this study, the relationship between genes and traits is an appropriate example of this dilemma, which is in urgent need of investigation.

The use of a pre- and post-test design combined with a discourse analysis of the teaching strategy during research lessons seems to be helpful in building a successively more accurate lesson design to achieve the object of learning. On a general level, we argue that the collaborative and iterative working model (learning study) used in this study is an important tool and has potential to scaffold teachers’ professional development; the teachers develop their pedagogical knowledge (e.g. variation of aspects for their discernment against an invariant background), their content knowledge (e.g. the relation between genes and traits), and their pedagogical content knowledge (e.g. how to design lessons that offer students the opportunity to express and develop their previous understandings and to understand whole/part relations and organizational levels).
That teachers’ content knowledge, especially their discernment of core ideas, increased and deepened during teaching preparation is not unusual (Berry, Loughran & van Driel, 2008). In this study the teachers gradually came to understand genetics more thoroughly, notably through less reliance on details and increased understanding of how these details relate to each other. In that respect the teachers themselves learned about the chosen object of learning in tandem with their students.

If professional development projects are to have substantial, sustainable, and long-term effects, teachers need to have access to more general models and pedagogical principles (Opfer & Pedder, 2011). In the study described here, using the learning study model, the basic principle of a collaborative and iterative working process accompanied by specific theoretical inputs seemed effective for students’ learning outcomes. The two main inputs in this paper were variation theory, with its focus on content and the discernment of critical aspects, and the sociocultural perspective, with its focus on artifacts and how critical aspects can be communicated and mediated in the classroom. We argue that teachers became more skilled in determining which aspects were critical to learning, more aware of the importance of varying such aspects, and more able to decide how these aspects should be varied and presented in a lesson design.

An ongoing difficulty in educational settings is the establishment of continuity between the details/parts and the whole of an object of learning. In this study, attempts to create a teaching strategy that helped students to use single concepts and to stretch them to coherent explanations became the focus of the lesson studies. During the third and successful research lesson, the teacher used a pictorial representation in which the single critical aspects for discerning the object of learning were offered in relation to the whole system simultaneously. For example, when talking about an aspect at the molecular level (allele coding for the production of melanin) the teacher continuously pointed out its expression at the organism level (the trait skin color); likewise, when focusing on an aspect at the organism level (trait) the teacher related it to its molecular antecedent (allele). In this way, the relationship between part and whole was continuously illustrated during the lesson. The focus was kept invariantly on the system, while the various aspects of the system were exemplified through chain-like story telling.

The explicit focus on relations between parts and wholes has been shown to be essential both in guided learning models (Kinard & Kozulin, 2008) and for the discernment of different levels of biological organization that are expressed with specific technical terms (Knippels, 2002). School science makes use of numerous technical terms in order to explain complex processes such as the relationships between genes and traits. However, technical terms are embedded in thematic patterns. In this case it was found that chromosomes and genes were important terms for understanding, but only if they were accompanied by the term allele. Learning study revealed this important aspect of learning this topic to the teachers. From this one example, whose results could be extended to other classes in genetics, learning study may be seen as a powerful tool for developing both teachers’ and students’ learning in areas previously found difficult to teach and to learn.

6. Implications

This paper describes how learning study can be used to develop pedagogical content knowledge and how, more specifically, it can contribute to teachers’ more developed awareness of learning through an analysis of iteratively developed teaching strategies. In this particular case, it was found that continuous links between single concepts and whole-process explanations are important to reduce possible confusion when factors vary. We found it was important to choose and vary only those factors critical to learning, and to keep non-essential factions invariant. The impact of continuous attention to the relation between the part and the whole is enhanced when it is mediated by a representation that focuses upon the critical aspects. Because biology is explained on a range of different organizational levels, it is important that the teacher make those levels explicit and focus attention on the level appropriate to the current lesson and the relation of that level to the other levels.
Note: Tables 1, 3, and 4 are modeled on those used in another manuscript aiming at describing students’ learning outcome (Holmqvist Olander & Olander, 2012).

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