Engaging in Educational Design Processes for Sustainable Learning: Learning and Becoming in Practice

Mona Holmqvist Olander and Clas Olander
University of Gothenburg, IDPP, Box 300, SE-405 30 Gothenburg, Sweden
mona.holmqvist@gu.se, clas.olander@gu.se

Abstract: The aim of this study is to describe in what way the students' learning outcomes and theoretical assumptions are used by teachers to enhance the design of lessons with a focus on development of sustainable learning over time. Seven teachers and 71 students in an upper secondary school participated, along with one researcher. Three lessons were designed and implemented in three different student groups (*N*=24, 23, 24), with one intervention for each group. The interventions were designed in an iterative process: the result of the first lesson formed the base for the development of the next, and so on. A multi-case analysis was conducted within and between each intervention. The results of the study describe correlations between teachers' deepened theoretical knowledge, changes in lesson design, and impact on students' learning outcomes in a long-term perspective. We found students' learning outcomes increased during the three interventions in three different groups of students (A +0.17, B +0.87 and C +1.54). At the delayed post-test, the learning gain in the third group sustained to be higher than in the previous two groups of students (A -0.08, B +0.26, C +0.75).

Survey of the Field

This study addresses a general issue in educational research, developing sustainable learning. Transfer is focusing how the things we learn in one situation affect our ability to handle other and new situations, related to what we have previously learned. Marton (2006) questions the assumption that transfer always builds on similarities (instead of differences) between different situations, that the similarity is defined by the researcher (not the participants), and that the relation is between two specific situations (rather than between "fields" of situations) should be questioned. Engle (2006) describes generative learning as the ability to appropriate the application of something in a new situation which differs from the first even when the first and second situations as such in some ways are related to each other. Our definition differs as we do not think it is enough to examine only two situations or to evaluate the learning in only one post-unit assessment activity. The design of assessing generative learning (learning that generates further learning) in our definition, means that we assess students' knowledge immediately before and after the intervention, which may be seen as one occasion (pre-test, intervention, post-test) because it results in a single analysis of the effect of the initial intervention. The weeks after the intervention, students participate in several different contexts, and they have the opportunity to discern the object of learning in other situations, depending on the degree to which the intervention has developed their potential generative learning. This can be seen as a second activity, which means we imply that the context the students meet after the intervention contributes to their learning. If their ability to learn further is enhanced by the initial lesson, their learning increases or sustains during the weeks and will be possible to assess in a new test several weeks after the initial intervention. As Carraher and Schliemann (2009) suggest, we have taken into consideration how prior knowledge plays a role in transfer; seeing transfer as a theory of learning there is a need to develop a hypothesis about what it takes to learn. This means that the instruction in the initial learning situation have an impact on the learning beyond the immediate learning situations if it is designed based on theoretical assumptions about learning. As the lesson forms students' prior knowledge in a new situation and opens up their ways of thinking about the content, different ways to design the lessons might have different impact on the learning outcome beyond the lesson, and that is what is studied in this project.

Purpose

The aim of this study is to describe in what way theoretical assumptions about learning and the students' learning outcomes are used by teachers to enhance the design of lessons with a focus on development of sustainable learning over time. Teachers' developed skills to design lessons in and by practice to enhance student learning is in focus. The design of the lesson plans are analysed together with the results of the students' learning outcomes in three different groups. By the use of an iterative process called learning study (Marton & Tsui, 2004; Holmqvist, 2011; Lo & Marton, 2011), three teachers teach three different lesson designs in three groups of students about the same content at three different lessons (one lesson in each group of students). The analysis of the learning outcomes and the design of the lessons are made collaborative in the whole team of teachers.

Theoretical Background

Variation theory (Marton & Booth, 1997; Runesson, 1999; Holmqvist, Gustavsson & Wernberg, 2008) has been used as the theoretical framework to design and analyse how students' generative learning is developed. In this framework, learning is seen as a qualitatively changed understanding of a phenomenon in the environment. This means that learning is an ongoing process where the learner gradually experiences instances in a more and more developed way. Learning is thus not seen as either correct or incorrect, for in all misconceptions there are some correct assumptions that can be developed. Variation theory is based on three corner-concepts: discernment, simultaneity, and variation. They all require each other in a learning situation and are intertwined. To learn something new, you have to discern this new part from a previously discerned background. This means you compare and see the new thing in contrast with other phenomena you have previously experienced. This variation makes it possible to suddenly experience something new in a former, familiar situation. In a very simplified way – you might not experience one particular house in a street that you travel every day until one day the owners repaint the house in a new colour. The variation of colour (once red and now yellow) makes you discern the house in a new way as you simultaneously remember what it looked like before and what it looks like right now. This theory has been used to develop learning in several different countries (Marton & Tsui, 2004), a number of different school subjects (Lo & Marton, 2011; Holmqvist Olander & Sandberg, 2013; Ljung-Djärf & Holmqvist Olander, 2013; Holmqvist Olander & Bergentoft, 2014), and beyond the bounds of the ordinary school (Holmqvist, 2009).

Multiple-Case study

The development of lessons designed for generative learning was studied in a multiple-case study (Stake, 2006), with three cases, called "learning study cycles" consisting of five steps each: design of one lesson, pre-test, intervention, post-test, and post-test session. The teachers' aim in the learning study was to develop learning designs in science education dealing with a general issue concerning students' learning of the "nature of science" (Lederman, 2007) with a specific object of learning, "What constitutes a scientific theory?" When the teachers discussed what topic to choose before the learning study, they agreed that the nature of science was a topic that was both challenging for them to teach and for students to learn; furthermore, it is a vital part of science subjects in Sweden (biology, chemistry, and physics). The learning study was enacted as part of a course in biology, where the idea of the nature of science is emphasised in the syllabuses, especially under the heading of "Character and working methods of biology," that is, "Models and theories as simplifications of the world – How they change over time" and "The importance of the experimental working process in testing, re-evaluating, and revising hypotheses, theories, and models."

Methodology, Participants, and Implementation

A learning study is a kind of action research; the learning study in this case was part of a school development project in an entire upper secondary school, where different subject-based teams of teachers chose different objects of learning. The participants were seven teachers, one researcher, and 71 students (approximately 17 years old) in three groups (N=24, 23, 24) in upper secondary school. Two group interviews about the content were conducted with equivalent students (N=8) who should not participate in the multiple-case study. The interview focused on probing students' views of how science could make claims and how you could judge whether a theory is scientific or not. It turned out that the students could rather easily spot whether a theory was scientific or not, but they were very vague when it came to reasons for their conclusions. The result of the screening was discussed at a meeting between the researcher and the teachers; the object of learning was formulated as "understanding what constitutes a scientific theory," instead of the previous focus on what a scientific theory is.

Data consisted of three videotaped research lessons in three different groups of students (taught by teacher A, B and C), pre-, post-, and delayed post-tests seven weeks after each intervention. There were also meetings (in total, six) before and after each lesson where teachers and researcher evaluated the previous lesson and suggested ways of communicating identified critical aspects in the next lesson. The data source for the teachers' experiences consisted of notes and minutes from six 2-hour meetings: 11/9, 27/9, 4/10, 9/10, 16/10 and 11/12 at the school. Between the meetings, the whole team of teachers assessed students' tests and, if possible, watched videos taken during the lessons. At least two teachers were also present during the research lessons, in that one was teaching and another was videotaping. The video-recordings represent an important data source since they point out in what way the teachers could become more skilled in designing the lessons based on students' previous knowledge.

Tests and Assessments

The teachers decided to teach about the nature of science. The idea of including the nature of science (NOS) in the science curricula is a worldwide phenomenon; however, there seems little agreement on what NOS is; Abd-El Khalick (2012) concludes that we currently "have no well-confirmed general picture of how science works, no theory of science worthy of general assent" (p. 354). However, some components seem inevitable, e.g. definitions and relationships between concepts, laws, models, and theories. Suggestions of constituents of a scientific theory include such aspects as being testable, replicable, and/or leading to predictions (p.737); they are fallible human constructions but have substantive evidence that supports them (Dagher, Brickhouse, Shipman & Letts, 2004, p. 739). This definition was the point of departure for teachers in this study, and the lesson designs are used as data to describe in what way the teachers develop their lesson design based on theoretical knowledge and the students' learning outcomes.

The pre-test, post-test, and delayed post-tests were identically articulated, although some students answered with paper and pencil while others logged on to a Web platform to enter and submit their answers. The analysis of results shows no difference in the way students answered regardless of response method. To keep the answers anonymous, students were given a three-digit code to be used on all three tests. The question was presented to students as shown in Figure 1.

What constitutes a scientific theory? Code:

I claim that the following examples are scientific theories.

(a) gravitation	(deals with the attraction of bodies to each other)
(b) telepathy	(deals with the transmission of thoughts)
(c) astrology	(deals with the influence of astronomical bodies on the life of humans)
(d) astronomy	(deals with the structure and motion of astronomical bodies)

Argue, i.e. give reasons, as to whether they are or are not scientific theories.

Figure 1. Pre-, post- and delayed post-test.

When assessing students' answers, we searched for the following criteria: A theory …

1) may be investigated/tested *and/or* be falsifiable.
2) is supported by previous findings.
3) may be used to make predictions.
4) may be modified and developed *and/or* the formulation is a human construct

Taking into consideration all four aspects of what a theory is would count as 4 points on the test, one point for each aspect. However, the assessment was not primarily based on a quantitative scoring; rather, the responses were analysed qualitatively to see in what way the students had developed understanding or not. Table 1 shows excerpts from one student's answers at pre- and post-test. The student has answered correctly as to whether the examples are scientific theories or not; however, the aspects she used to make these decisions resulted in different scores and showed (on the post-test) a deeper understanding that was beyond merely answering the direct question correctly.

Table 1: Answers from student #330

	Pre-test	Post-test
(a) gravitation	Yes, because the scientific arguments support the theory. (It is most likely, there is "evidence.")	Gravity is consistent with experiments and so on. You can try to contradict the theory but with no success. That is correct!
(b) telepathy	No, because there are no scientific arguments that support the "theory."	Experiment is not consistent with this hypothesis. There is no evidence that it is correct/there is evidence that it is wrong because the experiments are not consistent with the hypothesis. It's wrong!

Results

Differences in Teachers' Handling of the Content

Each lesson started with a brief introduction by the teacher and a framework of some aspects defining a scientific theory (hypothesis – testing – theory). After the introduction came a group activity where students in groups of three or four were given a "black box' (a large sealed box filled with unknown objects). The students were to figure out what was inside and give reasons for their assumptions (hypothesis). After that, the teacher made a PowerPoint presentation on the work of Ignaz Semmelweis and his hypothetic deductive method when trying to discover the cause of puerperal (childbed) fever. This part of the lesson resulted in a change of focus, as students became occupied in finding out why mothers died of puerperal fever instead of develop an understanding of what a scientific theory is. The teacher aimed to build a structure of relevance, but instead the students in lesson A and B became very focused on finding out why doctors in the 19th century could not stop the incidence of puerperal fever. The theory was kept in the background and the disease in the foreground. After this presentation, the framework was further developed on the whiteboard and related to the Semmelweis case. This was presented sequential in all three lessons, one at a time, instead of simultaneously or integrated. However, in lesson C the teacher made simultaneous references to the Semmelweis case when she drew the schedule on the black board.

At the end of the each lesson, the students were supposed to contrast what a scientific theory is with what it is not. In the first lesson (A), the example used was whether the theory of a flat earth could be considered as scientific; in lessons B and C, the contrast presented was between Semmelweis's theory and numerology. The flat earth theory was, however, all too clearly inaccurate to be a good example to find out if it is a scientific theory using the model drawn at the black board. This resulted in the teachers changing the example, in that way offering students a contrast between two phenomena from different areas. The strategy was to sharpen the contrast (Semmelweis versus numerology) even further in lesson C by also letting students do an online numerology test (http://www.twice.se/astro-numerologisk-kalkyl.html#.UhFRDD9YW2k).

Except for the difference in the examples of contrasts (flat earth and numerology); the main difference between the lessons lay in which aspects the teacher offered students when explaining what constitutes a scientific theory. This only took a few minutes of each lesson (five minutes in lesson B and eight in lesson C), but was the crucial part of the learning opportunity to understand what a scientific theory is, as the rest of the lesson was mainly about building a structure of relevance or background. In lesson A, there were few aspects of the structure devoted to the teacher explaining what a scientific theory is; the teacher mainly pointed out that observations lead to a hypothesis that could be tested and falsified or supported. During the post-lesson session after lesson A, the teachers decided to offer the students more aspects. This resulted in new dimensions of a variation of ways to reinforce a conclusion (experiments, earlier models, and predictions) which would lead to a generalisation and, finally, a theory. In lesson C, the pattern of variation was changed again, keeping the dimension of variation regarding the reinforcement but also opening up a dimension of variation regarding what a theory is (possible to develop, testable, and predictive). Thus, the analysis of teachers' intentions gradually includes all four aspects that constitute a scientific theory: (1) may be investigated/tested *and/or* be falsifiable, (2) is supported by previous findings, (3) may be used to make predictions, and (4) may be modified and developed *and/or* the formulation is a human construct. In lesson A, the aspects offered were about aspect (1), while the rest were not offered and therefore could not be discerned. The dimensions of variation opened up in lesson B, also concerning aspect (2) and (3); while in lesson C students had the opportunity to explicitly discern all four aspects and the teachers' intended or planned object of learning was thus closer to the enacted object of learning offered the students in lesson C than in lessons A and B.

Results of Students' Learning

Students' responses to pre-tests and post-tests (Table 2) show that students' learning gains in lesson A were low (and not significant, measured with paired t-test, 5%-level). However, their responses in lessons B and C were more in line with the scientific view after the lesson than before. This change is significant in both lesson B and C, but in lesson B the only category that the students seem to have discerned was "Scientific theories may be investigated/tested" (20 out of 23). After lesson C, the results show that the students in this group were able to give a more varied view; for example, 7 out of 24 argued with the help of three or four criteria, and another 10 students used two criteria (six students used only one criterion, and one failed to use any). Lesson C was also the lesson where students were able to retrieve developed knowledge after seven weeks; these students retained the knowledge over time and thus evidenced a more sustainable learning.

Table 2: Mean scores, differences, and range (0–4) in tests

	Research lesson A			Research lesson B			Research lesson C		
	Mean	Range	+/-	Mean	Range	+/-	Mean	Range	+/-
Pre-test	0.25	0–1		0.00	0–0		0.54	0–2	
Post-test	0.42	0–1	+ 0.17	0.87	0–1	+ 0.87	2.08	0–4	+ 1.54
Delayed post-test	0.17	0–1	- 0.25	0.26	0–1	- 0.61	1.29	0–4	- 0.79
Pre-test / Delayed post-test			- 0.08			+ 0.26			+ 0.75

In the results of the delayed post-test, we found a recession in all groups (from post-test to delayed post-test), but in lessons B and C there is an increased mean score in number of criteria mentioned when comparing pre-test and delayed post-test – specifically 0.26 in lesson B and 0.75 in lesson C (both significant). The students in lessons A and B did not retrieve more than one of the assessment criteria, however not necessary the same after as initially (as the student in Table 1). This was the same at the pre-test in lesson C, however in the post-test 10 students mentioned two criteria, four students mentioned three and three students mentioned all four criteria. At the delayed post-test, nine students mentioned two criteria and one student mentioned three criteria. The students in this group did develop a more differentiated knowledge then the students in the two other lessons.

Discussion

In this study, teachers' use of students' learning outcomes and gradually more developed theoretical knowledge about what it takes to learn have been studied. The design of the lessons became, over time, more and more explicitly focused on the aspects critical to discern for the students to enhance knowledge. The iterative process; plan, implement, assess, analyze and new planning based on the previous findings, enables a cumulative learning process for the teachers. When enacting the third lesson and making the contrast between Semmelweis and numerology; teachers opened up a dimension of variation where the two contrasting theories were offered to discern simultaneously. The increase of the students' learning outcomes was highest in the third lesson, supporting the hypothesis that teachers' developed understanding of what it takes to learn the defined content, and by that meeting the students' needs in a more powerful way, enhances student learning. When participating in a learning study, the first step is to articulate what you intend to teach and how (i.e. the intended object of learning), then put your knowledge into action in the classroom together with the students (i.e. enacted object of learning), and finally analyse the classroom practice through students' learning outcomes (i.e. lived object of learning). We argue that these steps are most effective if undertaken in authentic practice (Brown, 1992) and in a collegial context where in-depth discussions of teaching strategies are grounded in observation or video-recordings. In that respect, learning study as an in-service training model has potential for developing teachers' learning and becoming in practice regarding how to stimulate students to develop sustainable learning.

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