



HAL
open science

Upper secondary chemistry students in a pharmacochemistry research community

Lisette van Rens, Jacqueline Van Muijlwijk, Jos Beishuizen, Joop van Der
Schee

► **To cite this version:**

Lisette van Rens, Jacqueline Van Muijlwijk, Jos Beishuizen, Joop van Der Schee. Upper secondary chemistry students in a pharmacochemistry research community. *International Journal of Science Education*, 2011, pp.1. 10.1080/09500693.2011.591845 . hal-00721224

HAL Id: hal-00721224

<https://hal.science/hal-00721224>

Submitted on 27 Jul 2012

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



**Upper secondary chemistry students in a
pharmacochemistry research community**

Journal:	<i>International Journal of Science Education</i>
Manuscript ID:	TSED-2010-0417-A.R2
Manuscript Type:	Research Paper
Keywords :	chemistry education, design study, nature of science
Keywords (user):	

SCHOLARONE™
Manuscripts

Upper secondary chemistry students in a pharmacology research community

This study deals with the participation of ten upper secondary chemistry students, age 16-17, and their chemistry teacher in a pharmacology research community on anti-allergy medicines at University XX. Participation of the students in scientific research raises the question of how to bridge the gap between an upper secondary school inquiry practice and a scientific research practice. To bridge this gap, a design based on six principles derived from an educational model of a community of learners was proposed. The study firstly aimed at revealing whether the proposed principles were necessary according to the students, their teacher and three pharmacology researchers for successful participation of the students in the research community. Secondly, the study examined whether the students' understanding of discipline-specific content knowledge, interest in scientific research and knowledge about the nature of science changed during the course of the study. Data were obtained from questionnaires, interviews and video tapes. The results indicated that according to the teacher all six principles were necessary to bridge the gap, whereas according to the students one principle and according to the pharmacology researchers two principles were necessary but difficult to achieve. Furthermore, all students gained discipline-specific content knowledge. Their interest in scientific research exhibited a positive change and their knowledge about the nature of science increased. The implications for further research and practice are discussed.

Introduction

In efforts to implement inquiry based curricula in secondary school there has been a growing interest in studying students and teachers who are involved in authentic research activities (Krajcik, Blumenfeld, Bass, Fredericks, & Solloway, 1998; Kass, & Macdonald, 1999; Roth, 1996; xx, 2004; Windschitl, Thomson, & Braaten, 2008). This way, authenticity is considered as an approach to student learning by inquiry with the activities of researchers as a model for designing the inquiry-learning environment in class (e.g. Barab, & Hay, 2001). These activities also include the process by which the inquiry results are discussed and accepted in the research community (Driver, Leach, Millar, & Scott, 1996; Gilbert, 2004; xx, 2010; Wenger, 1998).

However, Helms (1998) concluded that modelling researchers' activities in class is not sufficient enough for upper secondary school students to gain an understanding of the scientific research practice. Helms (ibid.) argues that understanding the scientific research practice can best be achieved by students when they participate in a research laboratory or field setting; the participation model. Participation by secondary school students in a real research community raises the issue of how to bridge the gap between an upper secondary school inquiry practice and a scientific research practice (O'Neill, & Polman, 2004). In the current article, a study on necessary design principles to bridge this gap and the impact on the understanding of this practice by participating upper secondary chemistry students, age 16-17, is presented.

The study was guided by the following research questions:

- (i) which design principles are necessary for a successful participation of upper secondary chemistry students in an authentic research community?
- (ii) what changes occur in the students' discipline-specific content knowledge and interest in scientific research as well as in the students' knowledge on scientific investigation and NOS

1
2
3 by participating in such a designed community? The result of the study may contribute to a
4
5 research-based design that bridges the gap between an upper secondary school inquiry
6
7 practice and a scientific research practice in such a way that upper secondary chemistry
8
9 students who participate in the designed scientific research environment gain knowledge on
10
11 and interest in scientific research.
12
13
14

17 **Theoretical perspective**

18 *Design principles*

19
20 In the traditional view, scientific practices can fit within the methodological model of
21
22 knowledge production (Pera, 1994; Windschitl, Thomson, & Braaten, 2008). In this model
23
24 knowledge production is presented as an individual discovery in which scientists ask
25
26 questions, follow a standard method and obtain answers (Pera, *ibid.*). This is a view that is in
27
28 striking contrast to the contemporary views of 13 well-established scientists (Wong, &
29
30 Hodson, 2009). Wong and Hodson (*ibid.*) concluded that scientists view their practice as
31
32 community-bound and culture-based. Moreover, they stated that knowledge production occurs
33
34 in the discourse between members of the community. Pera (*ibid.*) depicts such knowledge
35
36 production in the dialectical model and argues that knowledge represents the agreement of the
37
38 scientists in the community, and in this sense, the scientists together invent rather than
39
40 discover nature.
41
42
43
44
45
46
47

48 Participation of students in a scientific research community aims at student learning
49
50 and therefore requires an educational model to inform our study. For student inquiry-based
51
52 learning in secondary science classes various studies propose to create a community of
53
54 learners in class (Brown, & Campione, 1996; Crawford, Krajcik, & Marx, 1998; Engle, &
55
56 Conant, 2002; Shulman, & Sherin, 2004). Brown and Campione (*ibid.*) indicated that in such
57
58 a community of learners, students are constantly involved in a recurring reflective cycle of
59
60

1
2
3 carrying out inquiry, sharing results, and applying conclusions with all three of these activities
4
5 related to key concepts from the scientific domain (see Figure 1).
6
7
8
9

10 [Insert Figure 1 about here]
11
12
13

14 The assumption behind the community of learners model is that students' inquiry
15 learning will be fostered by their involvement in carrying out inquiry if the inquiry process in
16 their science classes resembles a scientific research community.
17
18

19 If the core of a community of learners model is that students *carry out inquiry* tasks and
20 become actively involved in scientific research, then students should be considered as *serious*
21 *participants* in the process of scientific knowledge development. A process that should be the
22 responsibility of students and scientific researchers (Richmond, & Kurth, 1999). Moreover, if
23 students become involved in research on *key questions* in the respective science domain, then
24 they should have access to all relevant scientific *resources and apparatus* (Lave, & Wenger,
25 1991). They need to become familiar with the way of *collaboration and communication* in a
26 scientific research community (e.g., Driver, Asoko, Leach, Mortimer, & Scott, 1994). In
27 addition, if students participate in scientific research, demands are made upon their ability to
28 be critical of the research process they are involved in. Students have their thoughts of and
29 opinions on the way scientific research occurs and according to Mayer (2004) students start
30 reflecting when they notice that their views show conflict with reality. *Reflection* could start
31 as a more or less unintentional process by a feeling of discomfort (e.g. Schön, 1983) when
32 incongruence occurs between expectations about and experiences in a scientific research
33 practice. However, when reflection is seen as an ability to look forward and backward in order
34 to do something with a conflicting view then reflection could be an intentional process of
35 premeditated and directed effort (Brown, & Campione, 1996).
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 From the assumption behind the community of learners model and its derived
4 propositions we decided to design a scientific research community that is based on the
5
6 following principles:
7
8

- 9
- 10 1. Serious partnership in the process of knowledge development
- 11
- 12 2. Knowledge development occurs by doing scientific research
- 13
- 14 3. Key questions in the respective science domain are central
- 15
- 16 4. Acquaintance with collaboration and communication in a research community
- 17
- 18 5. Critical judgement by reflection
- 19
- 20 6. Access to scientific resources and apparatus
- 21
- 22
- 23
- 24
- 25
- 26

27 *Student discipline-specific content learning, interest in research and knowledge on NOS*

28
29 In this study upper secondary chemistry students participate in a pharmacology research
30 on anti-allergy medicines by means of designing, synthesising and testing medicines or
31 ligands that can block the production of histamine, an organic nitrogen compound that
32 triggers inflammatory response in the human body. For student discipline-specific content
33 learning we consider knowledge related to anti-allergy medicines (for example ligand,
34 receptor, blood-brain-barrier). To conceptualise how students learn in a scientific research
35 community, but now in a broader sense than discipline-specific content learning, we build
36 upon the socio-cultural perspective of Lave and Wenger (1991). In this perspective learning is
37 situated in co-participation of all researchers in the community by means of dialogue,
38 interaction and discussion between the members; a community of practice.
39
40
41
42
43
44
45
46
47
48
49
50
51
52

53 Furthermore, in the design part of a prospective medicine the students use a
54 sophisticated molecular modelling computer programme while in the synthesis part they use
55 organic synthesis laboratory apparatus as well as laboratory techniques like melting point
56 measurements. This is why, student research activities will be distinctly different from their
57
58
59
60

1
2
3 routine classroom practical work in which the students often just use recipes and simple
4
5 equipment to do experiments in order to verify theories (Cobb, & Yackel, 1996; Ritchie, &
6
7 Rigano, 1996; Richmond, & Kurt, 1999). Moreover, from an extensive literature review on
8
9 inquiry learning and teaching in science education Lunetta, Hofstein and Clough (2007)
10
11 concluded that secondary science students often follow a well-structured process of
12
13 identifying problems and formulating questions, designing and planning investigations,
14
15 collecting and analysing data, and so on. However, scientist hardly use such a well-structured
16
17
18
19
20
21 research process in their daily practice (Wong, & Hodson, 2009).

22
23 Sadler, Burgin, McKinney and Ponjuan (2010) found that most studies on
24
25 apprenticeship programmes, wherein students work with scientific researchers in a research
26
27 laboratory, address students' interest in science careers (e.g. George, 2006; Gibson, & Chase,
28
29 2002; Osborne, Simon, & Collins, 2003; Jenkins, & Nelson, 2005; Bennett, & Hogarth,
30
31 2009), but not their interest in scientific research as such.

32
33
34 Student understanding of NOS is not necessarily achieved when students carry out
35
36 inquiry activities in the classroom (e.g. Schwartz, Lederman, & Crawford, 2004; Ford, &
37
38 Wargo, 2007). Bell, Blair, Crawford and Lederman (2003) found hardly any change in upper
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
secondary school students' conceptions of scientific investigation and NOS during the time
that the ten students were engaged in a eight-week-long research apprenticeship programme.
They concluded that just carrying out inquiry activities is not sufficient for change and they
suggested as a remedy to embed explicit reflective sessions about scientific research and NOS
in the programme. In contrast, Richmond and Kurth (1999) who studied seven upper
secondary school students who participated in a seven-week-long residential summer research
programme, concluded that the apprenticeship itself as well as the guided reflection in journal
writing and regular group debriefing contributed to a greater student understanding of the
cumulative and continuous character of scientific knowledge. Moreover, they found that

1
2
3 because of the collaboration of the students and the researchers in the research community
4
5 and the degree to which the students could make use of resources within the community
6
7 contributed to their views of scientific practice and culture.
8
9

10 Few studies report on a significant change in student discipline-specific content
11
12 knowledge and student improvements in knowledge about NOS (e.g. Charney, Hmelo-Silver,
13
14 Sofer, Neigeborn, Coletta, & Nemeroff, 2007) when students are immersed in scientific
15
16 research practices, but hardly any studies report on student change in discipline-specific
17
18 content knowledge, change in knowledge about scientific investigation and NOS, and on
19
20 change in interest in scientific research. That is why we wanted to study these three aspects in
21
22 upper secondary chemistry students when they participate in a scientific research community,
23
24 that is designed according to the six proposed design principles derived from a community of
25
26 learners model.
27
28
29
30

31 From a designed pharmacology research community that is based on the six
32
33 principles we expect that upper secondary students who participate in such a community will
34
35 gain discipline-specific content knowledge and interest in research as well as knowledge on
36
37 scientific investigation and NOS.
38
39
40
41
42

43 **The designed pharmacology research community**

44
45 In four one and half hour meetings, we – a pharmacology researcher from University
46
47 XX, an experienced upper secondary chemistry teacher from a school in YY and one of the
48
49 authors – extensively discussed the six proposed design principles. In this setting the teacher's
50
51 role was to inform the researcher on the students' prior knowledge and abilities (c.f. Keys, &
52
53 Bryan, 2001; Eilks, 2003; Lotter, Harwood, & Bonner, 2007). Moreover, the teacher informed
54
55 his chemistry classes about the pharmacology research community and asked for ten
56
57 volunteers to join the community for a six days project lasting six consecutive weeks.
58
59
60

1
2
3 The outcome for each of the six principles will be briefly described in terms of the activities
4
5 of the students in the research community.
6
7

8 Regarding principle 1, *serious partnership in the process of knowledge development*,
9
10 while still at school the students read a flyer with information that the pharmacochemistry
11
12 researchers continue to search for anti-allergy medicines for for example hay fever. Moreover,
13
14 the flyer said that they would design and synthesise substances, prospective anti-allergy
15
16 medicines, that have never been synthesised before and that they would discuss the results of
17
18 their research in a poster session. Furthermore, the flyer told them that they would be working
19
20 with three researchers from the pharmacochemistry research community at University XX.
21
22 Before the start of the first meeting at our university the students told us that they understood
23
24 the information on the flyer and that it made them enthusiastic and curious about the
25
26 pharmacochemistry research.
27
28
29
30

31 For principle 2, *knowledge development occurs by doing scientific research*, at the
32
33 first meeting at the university the students, who were divided into two groups, made an
34
35 association map using provided concept cards. Both maps showed that students were able to
36
37 associate cards with concepts like hay fever, syndrome, source and anti-allergy drug, but that
38
39 they experienced problems in associating cards with concepts depicting the brain, neurons,
40
41 receptors and ligands. These outcomes were used by one of the pharmacochemistry
42
43 researchers to teach the students, in a lecture called ‘why drugs do work’, the working of an
44
45 anti-allergy medicine on a cellular and molecular level in a human body. Moreover, the
46
47 lecturer focused on ligands or histamine antagonists that fit on receptors in cell membranes so
48
49 that the production of histamine in the cell is minimized and on the research to find optimal
50
51 ligands that fit and block the histamine H₁-receptor but cannot pass the blood-brain-barrier,
52
53 since these ligands should not interact with brain cells.
54
55
56
57
58
59
60

1
2
3 Furthermore, the students discussed current models for histamine receptors **in cell membranes**
4
5 by studying an article by De Esch, Thurmond, Jongejan, & Leurs (2005), who are
6
7 pharmacology researchers at University XX.
8
9

10 During the design process the discussion of principle 2 unintentionally revealed that
11
12 the chemistry teacher and the pharmacology researcher **adopt** different stances as to the
13
14 function of laboratory work in a community of learners. The teacher sees laboratory work in
15
16 chemistry as a means to teach students a particular concept, as just one of the teaching
17
18 methodologies. On the other hand, the pharmacology researcher sees laboratory work as
19
20 a means of understanding what kind of knowledge the research **will reveal** as well as getting
21
22 to know how researchers think and work. This discussion concluded with the proposal **that** the
23
24 teacher **should** join the research community as a participant.
25
26
27
28

29 Regarding principle 3, *key questions in the respective science domain are central*, the
30
31 students and researchers discussed in three groups why cetirizine, the active substance in the
32
33 **anti-allergy** medicine, Zyrtec®, **acts** as a ligand **to** fit and block the histamine H₁-receptor but
34
35 cannot pass the blood-brain-barrier. Moreover, the groups made predictions with the use of
36
37 the histamine H₁-receptor model as is shown in the article of De Esch et al. (2005). **They**
38
39 **considered** whether variations in the carbon atom chain in the -N-(CH₂)_n-COOH group of
40
41 cetirizine can lead to ligands with an improved bonding capacity to the histamine H₁-receptor,
42
43 the latter being the research area in the pharmacology community.
44
45
46
47

48 For principle 4, *acquaintance with collaboration and communication in a research*
49
50 *community*, the students worked in teams of two with the three pharmacology
51
52 researchers. Each team used a modelling computer programme to build two different
53
54 molecular structures of varied cetirizine molecules, that were predicted as promising ligand
55
56 substances but had never been synthesised and tested in the laboratory before. Then, the teams
57
58 tested each molecular structure **proposed** by letting the computer programme, that contained a
59
60

1
2
3 model of a membrane with a histamine H₁-receptor in it, calculate the bonding capacity
4
5 between the cetirizine-like molecule and the receptor. After that each student synthesised and
6
7 purified in the laboratory one of the ligands that had a satisfactory bonding capacity. At this
8
9 stage of the project the students, in cooperation with the three researchers, used standard
10
11 organic synthetic pathways and procedures to purify the solid substances produced. Moreover,
12
13 each student verified the purity of the produced substance by a melting point measurement.
14
15 All pure substances were then sampled by the pharmacology researchers and subjected
16
17 to mass spectroscopy. Then, the spectra were used in the teams to verify the structures of the
18
19 various substances. After the decisions that the substances were pure and had the correct
20
21 structures, the bonding capacity of each substance was determined in vivo. These
22
23 measurements were done by the pharmacology researchers because in this part of the
24
25 research the safety rules do not allow the students to work in those laboratories. The bonding
26
27 capacities of all synthesised substances or ligands in relation to the membrane model were
28
29 discussed online with all members of the research community.
30
31
32
33
34

35
36 For principle 5, *critical judgement by reflection*, the teams prepared a poster on their
37
38 part of the research. In a poster session held within the faculty-wide pharmacology
39
40 research community, the students presented and discussed their results in relation to all
41
42 bonding capacities that were found and to the current model of the histamine H₁-receptor.
43
44

45
46 For principle 6, *access to scientific resources and apparatus*, the students had access
47
48 to all relevant scientific resources via an electronic learning environment. This Blackboard™
49
50 environment provided all tasks for the students. The students used it to submit their written
51
52 assignments. It served as a platform for the instructions and safety rules in the laboratory and
53
54 was used to present and discuss the results online. Moreover, the students had access to the
55
56 same apparatus and library resources as the pharmacology researchers.
57
58
59
60

1
2
3 The main student activities during their six weeks of participation in the
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

The main student activities during their six weeks of participation in the pharmacochimistry research community are summarized in Table 1.

[Insert Table 1 about here]

Methods, data collection and analysis

One upper secondary school was selected for participating in our study. This selection was based on two main criteria: it needed to be a school in the neighbourhood of University XX and the willingness of the chemistry teacher and ten of his students to participate in our study was important. The teacher had more than 25 years of chemistry teaching experience at upper secondary level and all students, age 16-17, were high ability students with two years of upper secondary chemistry education, but with hardly any experience in carrying out inquiry in chemistry classes. The motive for the pharmacochimistry researchers to join our study was twofold. Firstly, they expected to obtain research data in a very short time for ten substances or ligands related to the current histamine H₁-receptor model. Secondly, they were eager to show students, who still need to decide on their further education, that becoming a scientist is a good option.

In the study a combination of research instruments (Cohen, & Manion, 1994) with triangulations of data sources (Yin, 1994) was chosen, because we wanted to determine whether the six proposed design principles were successful in bridging the gap between a secondary school inquiry practice and a scientific research practice as well as whether any change occurred in student discipline-specific content knowledge, knowledge about research activities and NOS, and interest in scientific research.

For each research question, the instruments and the procedures of collecting and analysing the data are described in the next paragraphs.

The design principles

In week 6 of the project the ten students (S1-S10), their teacher (T) and three faculty researchers (R1-R3) were individually interviewed and asked to reflect on the extent to which each of the six design principles had been successfully brought into practice. Moreover, in the interviews with the teacher and the pharmacology researchers an extra question was asked about whether any principle was missing in the design. All interviews were audio taped and transcribed. Firstly, the fourteen transcripts were individually read by two of the authors. During this reading process a response was indicated with (√) when the interviewee expressed no doubt regarding the achievement of a particular design principle. Responses with some doubt were indicated with (±) and responses full of doubt with (-). Secondly, the indications in the ten student transcripts were separately assigned for each of the six design principles with 10 when all students agreed and with for example 4 when four students agreed on the achievement of a particular design principle. The same was done with the indications of the teacher and the three researchers.

Field notes were made by one of the authors for the instructional strategies of all the pharmacology researchers in week 1-6 by recording all activities of the researchers at each session. Moreover, all these activities were videotaped by the note-taking author. Furthermore, another author observed four randomly chosen students (named S1, S2, S3 and S4) in pairs during their main activities in week 1-6. The observations included the recording of what the four students did on a certain day at a specific time. Those four students were also videotaped during the main activities. The videotaping was monitored by the author who also did the capturing of the researchers' instructional activities. The sections where the analysis of the data regarding the six proposed principles in each group of participants showed discrepancies were compared with the written field notes and the relevant transcribed video tape recordings.

1
2
3 All data analyses were compared by two of the authors and discussed until consensus
4 was reached (Janesick, 2000).
5
6
7
8
9

10 *Student change*

11
12 To determine change in **student** discipline-specific content knowledge, **student** knowledge
13 about scientific investigation and NOS as well as change in **student** interest, we used a
14 questionnaire, a semi-structured interview and the earlier mentioned video recordings in our
15 study.
16
17
18
19
20
21

22 The questionnaire, that was filled in by all ten students in week 1 and 6 of the study
23 consisted of three Parts (I-III); see the Appendix.
24
25

26 In Part I of the questionnaire the students answered ten open questions that are related to
27 discipline-specific content knowledge. For each question an answer led to **a mark between 0**
28 **and 10**. The total scores of the students in week 1 and 6 were averaged for each question and
29 for all questions as well as for the change between week 1 and 6.
30
31
32
33
34

35 In Part II of the questionnaire the students rated, on a four-point Likert scale, eleven
36 statements on interest in scientific research. For some examples see Part II of the Appendix.
37
38

39 This part of the questionnaire was piloted previously with 68 upper secondary chemistry
40 students (age 16-17) from the same school ($\alpha = 0.82$) **since it was set by the authors who**
41 wanted to assure the reliability and validity of this part of the questionnaire.
42
43
44
45
46

47 All student ratings **were allocated 1, 2, 3 or 4 points, then all points for each statement in the**
48 **questionnaire were added and averaged. Followed by a comparison of the students averaged**
49 **scores in week 1 and week 6.**
50
51
52
53
54

55 In Part III of the questionnaire the students answered six open questions (see Part III of the
56 Appendix). In the first question the students were asked to write down as many activities as
57 possible that they consider to be scientific investigation activities. Then, they answered four
58
59
60

1
2
3 questions concerning scientific knowledge, scientific theories, difference between a scientific
4 theory and a scientific law, and creativity and imagination of scientists. These four questions
5 were taken from the Views of Nature of Science Questionnaire Form C (VNOS-Form C;
6 Abd-El-Khalick, 2006). **Finally**, they answered question 6 on: 'Why do scientists use
7 models?'

8
9
10 The answers of the ten students to the six questions were analysed in different ways. First for
11 question 1, the average number of research activities given by the students in week 1 was
12 compared to those given by the students in week 6. Secondly, two researchers categorised the
13 student written responses (to question 2-6) **as a naïve understanding** (a correct answer but an
14 incorrect reasoning) and **an informed understanding** (a correct answer and a correct reasoning)
15 **analogous** to Abd-El-Khalick (2006).
16
17
18
19
20
21
22
23
24
25
26
27
28

29
30 In week 6, three days after the presentations, the four randomly selected students (S1-
31 S4) were individually interviewed by one of the authors. Each interview took about two
32 hours. During the interview the written responses in the questionnaire from week 1 and week
33 6 as well as the video tape of that student were at hand. First, we pointed out to the
34 interviewee where he made changes regarding the questions in Part I, II and III of the
35 questionnaire. Second, we asked the question 'what caused the change?' Then, if possible, we
36 looked up the relevant video recording and asked the interviewee to 'explain why he changed
37 his mind?' The four interviews were audio taped and transcribed.
38
39
40
41
42
43
44
45
46
47

48 All data analyses were done by two of the authors and discussed until consensus was
49 reached (Janesick, 2000).
50
51
52
53
54

55 Results

56 First, the results of the achievement of the proposed six design principles for the
57 pharmacochemistry research community are presented. Then the results are shown of change
58
59
60

1
2
3 in **student** discipline-specific content knowledge, **student** interest in scientific research and in
4
5 **student** knowledge on scientific investigation and NOS.
6
7

8
9
10 *The design principles*

11
12 The analysis of responses of the ten students, their chemistry teacher and the three
13
14 pharmacology researchers in the interviews during week 6 reveals that all participants
15
16 expressed no doubt regarding design principle 2, *knowledge development occurs by doing*
17
18 *scientific research*, principle 4, *acquaintance with collaboration and communication in a*
19
20 *research community*, and principle 6, *access to scientific resources and apparatus*. Moreover,
21
22 the analysis reveals that the teacher expressed no doubt regarding all design principles.
23
24 However, **differences** were identified in the responses of the students regarding design
25
26 principle 3, *key questions in the respective science domain are central*, as well as in the
27
28 responses of the researchers on design principles 1, *serious partnership in the process of*
29
30 *knowledge development*, and 5, *critical judgement by reflection*. For the analysis of all
31
32 responses see Table 2.
33
34
35
36
37
38
39
40

41 [Insert Table 2 about here]
42
43
44

45 Our analysis shows that four students (S4, S7, S8 and S10) indicated some doubt
46
47 regarding the achievement of design principle 3, *key questions in the respective science*
48
49 *domain are central*. An example is shown from the transcript of one the interviewed students
50
51 (S4):
52
53
54
55

56
57 I found it a very intriguing research question and they [the researchers] told me that their
58
59 research is in a crucial area of getting to know more about allergies and how to stop them. I
60

1
2
3 see the relevance of this research, but by now I really do not know whether studying these
4
5 processes in the [cell] membrane are the most important ones in their area.
6
7
8
9

10 Further analysis of the field notes does not give more information on design principle 3.
11 However, the transcript of the part on the video tape in which student (S4) and researcher
12 (R2) are talking about the relevance of the research reveals that the student asked for the main
13 reason of the research, but does not receive an adequate answer. The transcript is as follows:
14
15
16
17
18

19
20
21 S4: Yes, I understand the importance of helping people who suffer from hay fever, but
22 what is the overall reason [of your research]?
23
24

25
26 R3: To know more about processes in the cell membrane, what molecules trigger or stop a
27 process inside a cell.
28
29

30 S4: So, all researchers in your division look at models of cell membranes?
31

32 R3: Yes, ...
33
34
35
36

37 In the analysis of the researchers' interviews also some doubt was identified in one of the
38 responses of the pharmacology researcher (R2) regarding design principle 1, *serious*
39 *partnership in the process of knowledge development*, as is shown in the following quote:
40
41
42
43
44
45

46 R2: Especially in the laboratory. At a certain moment during the instruction, they [the
47 students] started a discussion on acids, bases and on our accepted procedure of
48 synthesising a ligand. At that time I was astonished about their lack of knowledge. I
49 just instructed them what to do instead of creating room for a discussion on the
50 zwitterionic character of the various histamine H₁-ligands related to the predictions of
51 histamine H₁-receptor model. I think I did this because of time pressure.
52
53
54
55
56
57
58
59
60

1
2
3 Moreover, the written field notes during that particular instructional activity of researcher R2
4
5 were: ‘cuts off discussion’, ‘students fall silent’, and ‘five students start reading the lab procedures’.
6
7
8 And from the analysis of the video fragment of that activity we agreed upon: ‘researcher
9
10 hesitates when students ask **about** the neutralising effect of a carbonic acid, after a few seconds her
11
12 face reassumes a normal expression and she gives instructions with a louder voice on the procedure of
13
14 the planned synthesis of a ligand’.
15
16 Furthermore, the analysis of the researchers’ interviews reveals some doubt in one of the
17
18 responses of the pharmacology researcher (R3) regarding design principle 5, *critical*
19
20 *judgement by reflection*, as is shown in the following quote:
21
22
23
24
25

26
27 One of the students [S7] unexpectedly got a liquid instead of a [predicted] solid [ligand]. This
28
29 student saw that all other students got solids. This fact did neither trigger reflection by the
30
31 student on the research method, the prediction, or hypothesis related to the model nor bring
32
33 about a critical attitude of the student. The student just seemed to be worried of not finding a
34
35 correct answer.
36
37
38

39
40 Further analysis of the field notes and videotapes does not give more information on the issue
41
42 of principle 5.
43

44
45 Finally, the interview responses of the teacher and the three pharmacology
46
47 researchers show that they experienced no missing **principles in the design of a research**
48
49 **community that was based on six design principles derived from an educational model of a**
50
51 **community of learners**.
52
53
54
55

56 *Student change in discipline-specific content knowledge*

57

58
59 The total average of the student scores in Part I of the questionnaire **worth 10 points**, showed
60
an increase of 4.94 points; from an average score of 2.73 points scored by the students in
week 1 to 7.67 points, scored by the students in week 6 (see Table 3).

[Insert Table 3 about here]

From the comparison of the written responses in week 1 and week 6 from the questionnaires of students S1-S4 we noted that all four students had a correct change of response for question 1 (what is a ligand?) and 2 (what is a receptor?). Moreover, students S2 and S4 had a correct change for question 3 (Describe in brief how cells communicate). From the interview data we obtained that these changes were mediated by one of the pharmacology researchers, who gave a lecture in the first meeting (week 1) immediately after the students made an association web with provided concept cards. As student S4 expressed it:

In our group we did not know what to do with those cards [cellular and molecular level], but after she explained it [in the lecture] I understood the meaning of a ligand, receptor and also how cells communicate.

The concept of a spacer (question 8) and how the bonding capacity of the ligand is measured (question 10) also changed for all four students to a correct answer in the written responses from week 6. The interview data indicated that they had grasped the concept of a 'spacer' when they did the modelling activity in week 2. The correct answer to question 10 was acquired by students S1 and S3 through the online discussion in week 5 and by students S2 and S4 during the preparation of the poster presentation in week 6.

Student change in interest in scientific research

From all student responses in Part II of the questionnaire we observed that none of the eleven statements had a negative change (see Table 4). As shown in Table 4 positive changes

1
2
3 occurred in statements 1, 3, 5, 8 and 11 (see the Appendix). Moreover, the total average score
4
5 of the students' interest in scientific research changed from 3.47 points in week 1 to 3.60
6
7 points in week 6. No changes occurred in statements 2 (doing scientific research needs
8
9 patience), 4 (doing scientific research is hard work), 5 (doing scientific research is
10
11 cumbersome), 7 (all scientific research is interesting), 9 (I like hearing about scientific
12
13 research on TV) and 10 (I find scientific research interesting). For the latter it should be noted
14
15 that there was no positive change possible, because in week 1 the average students' score was
16
17 already 4.0 points, which is the highest possible score.
18
19
20
21

22 Analysis of the interview transcripts showed that the change for student S1 for
23
24 statements 1 and 11 was because of:
25
26
27
28

29 I thought of studying economics, so I was not so eager to learn about scientific research, but in
30
31 fact there are two reasons why I changed my mind. I am very excited about hovering between
32
33 what we know and what we do not yet know and during lunchtime I also talked to some of the
34
35 master students about their experiences in studying biomedicine. That is why I changed my
36
37 mind and therefore I also changed my choice of what to study at university. I think I will opt
38
39 for a study in chemistry or biophysics.
40
41
42
43

44 Furthermore, student S2 expressed his change of response to statement 11 like this:
45
46
47
48

49 It was such an interesting experience, the discussions, the new stuff, for example how long it
50
51 takes to have a new medicine. I want to be part of that world, so I am really convinced I want
52
53 to become a scientist and not a lawyer. I really like the way they [the pharmacology
54
55 researchers] approach problems. Their world is exciting and requires patience, that is what I
56
57 like.
58
59
60

1
2
3 Student S3 responded, regarding statement 8, as follows:
4
5
6
7

8 I wish I could have put a 'fully agree' on some of those [the statements]. It was great to be part
9 of real research. For example, the labs and the apparatus and also all the discussions we had.
10 You know you can just talk to them [the pharmacology researchers]. Before the project I
11 thought they would be more like nerds. I hope our teacher also learned something so that we
12 have more real practical work in class [statement 8]. Normally I am a bit ahead in our
13 [text]book so the experiments we do in class are really very eh very dull.
14
15
16
17
18
19
20
21
22

23 Lastly, student S4 changed his views on statements 3 and 5 as is evidenced by:
24
25
26
27

28 It was a great experience to be here at your university. I changed [statement] 3 to agree and
29 [statement] 5 to disagree, because at school I sometimes feel that the work in the lab is very
30 dull. We just copy what is in the [text]book. Here our work was exciting and for the first time I
31 was really challenged in my thought process. I learned a lot in a short time.
32
33
34
35
36
37
38

39 *Student change in knowledge on scientific investigation and NOS*

40
41 In Part III, regarding question 1 "write down as many activities you consider to be scientific
42 investigation activities", the average number of investigative activities that were mentioned
43 by the students increased from 5.5 (week 1) to 8.7 (week 6).
44
45
46
47

48 In week 1 the students referred to activities, such as: 'formulating research questions',
49 'planning and conducting experiments', 'finding results', 'inferring conclusions' and 'writing
50 reports'. The increase in week 6 was brought about by additional activities related to models
51 'using and adjusting models', to creativity 'thinking about various aspects of unexpected
52 outcomes' and to communication 'not only presenting results but also discussing the results
53 with peers and other researchers'. Furthermore, from a comparison of the students' written
54
55
56
57
58
59
60

1
2
3 responses (from S1-S4) in week 1 and week 6 we noticed that student S1 and S4 added extra
4
5
6 investigative activities. In the interview S1 expressed it as follows:
7
8
9

10 At school we learn the scientific method, which is a stepwise process. That is why I wrote
11
12 down those ones [written responses in week 1]. But now I understand that it is not like that. I
13
14 experienced research as a hotchpotch that you have to think over and over. We only used the
15
16 steps in our poster.
17
18
19
20

21 And this is how student S4 expressed it in the interview:
22
23
24
25

26 I now think that communication is very important, because I saw that they [the
27
28 pharmacochemistry researchers] kept on talking about our results and they argued about what
29
30 other researchers would think of a possible overlap between two models.
31
32
33
34

35 Students S2 and S3 did not add extra investigative activities in their written responses in week
36
37 6. Both reasoned in the interview like this:
38
39
40
41

42 Those were the items we used to prepare our research poster. We also use those at school.
43
44
45

46 The students' written responses to question 2 indicated that in week 1 all ten students
47
48 thought that the only way to develop scientific knowledge was through experiments. The
49
50 examples they wrote down were **for example** 'electrolysis' (S1), 'mixing alcohol and water' (S4)
51
52 and 'making aspirin' (S8). However, seven students indicated in week 6 that observation also
53
54 can lead to scientific development. These are, **for example**, two responses:
55
56
57
58
59
60

1
2
3 S9: Not always, I believe that not only observations but also thinking can give knowledge
4 development in the sciences. For example with the black holes they cannot do
5 experiments.
6
7
8

9
10 S10: No, some problems, for example the carbon dioxide pollution in our world, are so
11 complex that scientists cannot do valid experiments.
12
13

14
15
16 Two of the remaining students (S5 and S6) again responded that experiments are the only way
17 to develop scientific knowledge and one student wrote:
18
19

20
21
22
23 S8: Experiments are not carried out to develop knowledge but to verify knowledge, like
24 we did with the predictions we made with the membrane model.
25
26
27

28
29
30 From the interview transcripts we obtained the following quotes about question 2:
31
32

33
34 S1: I changed because during the modelling [activity] I realised that some parts in the
35 model are assumptions and do not come from experiments;
36
37

38
39 S3: Experiments are not always possible, because sometimes the problem is too complex
40 to handle all the variables. I changed my mind when we [with student S10] discussed
41 aspects concerning climate change, which was when long-term observations could
42 help to find explanations;
43
44
45

46
47 S4: We do real experiments in which we control everything and we do thought
48 experiments based on observations; both are needed to further build on our
49 knowledge. I changed because I discussed this with my teacher, who told me that you
50 need both.
51
52
53

54
55
56
57
58
59 The students' written responses to question 3 showed that in week 1 all ten students
60 think that a scientific theory does change. Some responses:

1
2
3
4
5
6 S1: Yes, theories can change. Like the evolution theory has changed over the years.
7

8 S4: Yes, theories can change. The atomic theory developed because scientists build on the
9
10 knowledge of their predecessors every time.
11
12
13

14 In week 6 all students again wrote that a scientific theory can change. The responses of four
15
16 students, S1, S2, S3 and S8, changed:
17
18
19
20

21 S1: Yes, they change. In the beginning of the project I thought that most scientific
22
23 theories, like the evolution theory, changed in earlier days and are stable by now, but
24
25 now I think that scientists have another meaning to that word than I had at that time;
26
27

28 S2: They change. I now see a theory as something that is accepted by scientists;
29

30 S3: Yes, I think that a theory can change but some theories (for example the atomic
31
32 theory) resists, for the time being, attempts to disprove them;
33

34 S8: A definite yes, theories are susceptible to new evidence. Scientists constantly think
35
36 them over.
37
38
39
40

41 Further evidence for students' ideas about scientific theories was provided by their responses
42
43 in the interview, abstracts of which are quoted below:
44
45
46
47

48 S1: As I understood from him [R3] theories are explanations and I think they can change
49
50 when you know more;
51

52 S2: During the synthesis of the ligand we had to wait so we had a discussion with I. [R2]
53
54 and K. [student S1] on theories and from that I learned that an explanation is in fact a
55
56 theory;
57
58
59
60

1
2
3 S3: The ligand I synthesised in the lab did not show the bonding capacity as was expected
4
5 by the calculations of the computer, so in the poster presentation it became clear to me
6
7 that we disproved something, so maybe the theory can change;
8

9
10 S4: When you know more about how a ligand works you can change the theory of the
11
12 interaction between a ligand and a receptor and how it affects the inside of a cell.
13

14
15
16 In week 1 all students' written responses to question 4 relate to the consideration that
17
18 theories later on when there is more evidence become laws. By week 6, the student responses
19
20 except for student S1's response did not show any change. In week 6 student S1 wrote:
21
22

23
24
25 A theory is something else than a law, more evidence does not automatically lead to a law.
26
27

28
29
30 In the interview student S1 responded as follows:
31
32

33
34 I first thought that more evidence always leads to a law, but now I think, because of I. [R2]
35
36 who convinced me, that more evidence gives better explanations. Whereas I consider a law as
37
38 something that when you do A it always will lead to B; like an apple will always fall down.
39
40
41

42
43 Students S2, S3 and S4 all expressed it in the interview more or less like:
44
45

46
47
48 Yes, more evidence will always lead to laws, because like Ohm's law came from many
49
50 experiments that all came to the same conclusions.
51
52

53
54 Student responses to question 5 showed that all students in week 1 think that creativity
55
56 and imagination is 'not done', because like four of them (S1, S3, S6 and S8) wrote: 'science
57
58 should be objective, not subjective'. However, all ten students felt in week 6 that scientists
59
60 need creativity and imagination. Some written responses are:

1
2
3
4
5
6 S6: Yes, because for explanations you need to have ideas that come from your brains as
7 well as out of discussions with your peers;
8

9
10 S8: Yes, when one of us in the lab got a liquid instead of a solid I saw the function of
11 creative thinking immediately the question why was asked and they [R1, R2 and R3]
12 started imagining all kinds of explanations.
13
14
15
16
17

18
19 Quotes from the interviews confirm these ideas:
20
21
22

23 S2: You know I first thought of something like a kind of creative bookkeeping and that is
24 not allowed in research. But by the time that we [S2 and S7] had to prepare our poster
25 we discussed that for each and every part in a research you need to be creative. I mean
26 not in a sense that you mislead other researchers but that you keep on thinking and
27 also keep on using your imagination;
28
29
30
31
32
33

34 S3: At the start of the project I felt that researchers should be honest people. They cannot
35 just direct what results should come out of their research. But now I think that
36 researchers should be creative. Especially when I ran into problems with some of the
37 glassware we used. Then they came up with a good solution;
38
39
40
41
42

43 S4: I changed because I had a discussion with I. [R2]. He said that Einstein used a lot of
44 imagination and creative thinking when he developed $E = mc^2$. I also talked about it
45 with my mother [who is a dentist]. I experienced a big difference between our
46 chemistry lab work at school and real research. At school we just verify things like we
47 did in electrochemistry, but now I saw how they think.
48
49
50
51
52
53
54
55

56 Regarding the students' written responses to question 6, all ten students referred in
57 week 1 to scale models: 'so to have an idea how molecules are ... like the [molecular] model boxes
58
59
60

1
2
3 we have at school to build methane', whereas in week 6 all students' written answers contained
4
5 the notion of the predictive function of models.
6
7

8 The responses in the interviews were all related to the predictive function of models in
9
10 relation to the results of the bonding capacity of the synthesised ligand to the cell membrane,
11
12 a change that according to the students came through the activity of predicting with and
13
14 reflecting on the model. As S1 expressed it:
15
16

17
18
19 We used the model to predict and the results of the experiments to reflect on the model,
20
21 because it [the model] catches part of a reality.
22
23

24
25
26 The results of the categorised students' responses to question 2-6 (Part III of the
27
28 questionnaire) are summarised in Table 5.
29
30

31
32
33 [Insert Table 5 about here]
34
35

36 37 38 **Discussion, conclusion and implications**

39 40 41 *Design principles*

42
43 The first research question in our study was: 'which design principles are necessary to have a
44
45 successful participation of upper secondary chemistry students in an authentic research
46
47 community?' Firstly, using the six principles (1-6) that are proposed by the community of
48
49 learners theory we succeeded in designing an authentic research community project in which
50
51 we expected that upper secondary chemistry students could successfully participate.
52
53 Secondly, data from the interviews with the chemistry teachers and the three
54
55 pharmacochemistry in week 6 show that no new design principles came up.

56
57 Using the data obtained in the interviews regarding the experiences of the different
58
59 participants in the research community on whether the six intended design principles were
60
successfully brought into practice, it can be concluded that in general most of the principles
were experienced as intended by most of the participants (see Table 2). However, for

1
2
3 principle 1, *serious partnership in the process of knowledge development*, we conclude that, at
4 that particular time, there was a mismatch between one of the pharmacology researchers
5 and the students regarding the level of the students' understanding of the various histamine
6 H_1 -ligands and the histamine H_1 -receptor model. A reason for this mismatch could be that this
7 researcher expected that the lecture at the start of the project was sufficient for the students to
8 understand these. Moreover, for principle 5, *critical judgement by reflection*, the interview
9 data show that one of the pharmacology researchers realised that an unexpected result
10 was not enough to start a process of reflection within one of the students. An explanation
11 could be that this particular student reflected his experiences from laboratory work at school,
12 **for example** they do laboratory work to verify a concept, they hardly are challenged to think
13 critically, and they just try to give a right answer. The first example, **students do laboratory**
14 **work to verify a concept**, maybe reflects **his** teacher's view on the role of laboratory work. **A**
15 view that was visible during the process of designing the research community, in which the
16 teacher **views laboratory work as a kind of methodology to develop concepts**. That teachers
17 view laboratory work **as a means** to develop concepts **only** was also concluded by
18 Gyllenpalm, Wickman and Holmgren (2009).

19
20
21 Furthermore, from the student interview data, it is concluded that regarding principle
22 3, *key questions in the respective science domain are central*, four students understood the
23 question under research in the pharmacology community but felt that a bigger view
24 regarding the science domain was not clarified **for** them. This is probably due to the fact that
25 the pharmacology researcher at that time in the laboratory **was not aware of the gap**
26 **between the thinking of the student who focussed on the macro-level ('helping people who**
27 **suffer from hay fever')** and his own thinking that focussed on the micro-level ('**what**
28 **molecules trigger or stop a process in a cell')**.

29
30
31 **In conclusion**, the six principles in general seem to be feasible for designing an
32 authentic research community that can bridge the gap between science laboratory work at
33 upper secondary school and research at university.

34
35
36 *Student discipline-specific content knowledge and interest in scientific research as well as*
37 *knowledge on investigative activities and NOS*

38
39
40 The second question in our study was: "what changes occur in the students' discipline-
41 specific content knowledge and interest in scientific research as well as knowledge on
42 scientific investigation and NOS by working in such a designed community?"

1
2
3 Using the results obtained from the student data in Part I of the questionnaire, we
4 conclude that the discipline-specific content knowledge of all students increased (see Table
5 3). The most remarkable increase in their knowledge regarded questions 10, *explain how the*
6 *bonding capacity of the ligand is measured*, and 7, *explain the working of a medicine on*
7 *cellular level*. Hence, participation in the pharmacochimistry research community enhanced
8 discipline-specific content knowledge development within all students.

9
10 From the student interview data, we conclude that the following activities enhanced student
11 discipline-specific content knowledge:

- 12
13
14
15
16
17 (i) the ‘concept mapping’ activity followed by a lecture. In this activity the students
18 realised that they had gaps in their knowledge regarding the cellular and molecular level.
19 This awareness raised their anxiety about the pharmacochimistry research;
20
21 (ii) the ‘modelling’ activity. This activity enhanced the student understanding of the concept
22 of a spacer, because the students individually built a variation of the spacer part in a
23 cetirizine-like molecule; and
24
25 (iii) ‘reflective’ activities such as the online community peer discussion of the results from
26 the in vivo experiments and the preparation of their research poster.
27
28
29
30
31

32 Regarding student interest in scientific research the obtained data in Part II of the
33 questionnaire show small but positive changes for statements 1, 3, 5, 8 and 11 (see Table 4).
34 Remarkable is that the students gave the highest possible score for statement 10 that says ‘I
35 find scientific research interesting’. Moreover, at the start of the project the average student
36 interest ratings on the eleven statements were already quite high; 3.47 on a four-point Likert
37 scale. We think that this high value is due to the fact that the students who participated in our
38 study did this on a voluntary basis and in fact were already, as is shown by the results of
39 statement 10, very interested in scientific research. When we take this into account, then the
40 average student interest rating to 3.60 at the end of the project is remarkable since to increase
41 the interest of already highly-motivated students is not likely to be easy.
42
43
44
45
46
47
48
49

50 The student interview quotes, regarding Part II of the questionnaire, show that the
51 student changes in interest were mainly brought about by talking to other students at the
52 university, by actually participating in the field of scientific research, by experiencing the
53 environment at the university as exciting, by facing the challenges of and problems in
54 scientific research as well as by experiencing the research culture. The follow-up of the two
55 students who said that they wanted to change to a science career, revealed that one student
56 studies biophysics and the other student studies chemistry.
57
58
59
60

1
2
3 From the students' written answers to question 1, that were obtained from Part III of
4 the questionnaire, we conclude that at the end of the project the students were able to refer to
5 more investigative activities. Some students recognise that scientific research is not just a
6 method or a stepwise process, whereas some students still consider it as a good structure to do
7 investigative work and to prepare a poster. Moreover, some students realise that the
8 researchers judge the status of method and of scientific knowledge in the context of its use.
9

10
11
12
13
14 Based on the written responses regarding student knowledge on NOS in Part III of the
15 questionnaire (see Table 5) and on the student interview data, we conclude that all students
16 changed toward an informed view regarding two NOS aspects, namely 'creativity and
17 imagination' and 'models'. The change on the first aspect occurred through reflective
18 moments during discussions, by seeing a completely different attitude of the
19 pharmacology researchers when unexpected results (for example the formation of a
20 liquid) came up. The researchers discuss possible explanations for unexpected results in stead
21 of rigging results so that they fit the predictions. Therefore, role modelling by researchers
22 seems to be a crucial element to enhance a change. The student change of the second aspect
23 occurred through predictive and reflective activities regarding the histamine H₁-receptor
24 model. Hence, a community-wide peer prediction on the outcome and peer reflection on the
25 results and the method in relation to the model under research appeared to be an effective
26 approach to change students' views on models.
27

28
29
30
31
32
33
34
35
36
37 Table 5 shows that change in students' views on the difference between a theory and a
38 law was difficult to achieve. Only one student (S1) changed to an informed view, and this was
39 as the student interview data show, because of a discussion with one of the
40 pharmacology researchers. The other students did not change their views, because the
41 synthesis of a ligand is probably not a good example of being confronted with the difference
42 between a theory and a law in laboratory work. As such this question is not so relevant for our
43 study. More explicit reflective discussions could, according to Yacoubian and BouJaoude,
44 2010, be more effective in changing student views regarding the difference between a theory
45 and a law.
46

47
48
49
50
51
52
53 For the other two NOS aspects 'requirement of experiments' and 'change in theory' we
54 obtained mixed results (see Table 5). From these results we conclude that it is difficult for
55 students to change these aspects. Even their serious involvement in and ownership of the
56 research was not enough for some of the students to change their views on these two aspects,
57 which shows that the students should probably be more involved in activities that show that
58 experiments are not the only route to scientific knowledge, but also show the role of
59
60

1
2
3 induction. In order to create student awareness on the idea that scientific knowledge is based
4 on the non-observable as well. Moreover, students could do activities regarding the difference
5 between non-tentative scientific facts and tentative scientific theories.
6
7

8
9 Of course, awareness is needed that participation of students in a scientific research
10 community, that brought about the change in students' interest in scientific research, is
11 difficult to achieve in common upper secondary schools (Buxton, 2006). Nevertheless,
12 looking at the results in which the students express their experiences with laboratory work at
13 school, we agree with Millar, & Abrahams (2009) that it is a necessity to change the way
14 practical work is presented at secondary schools.
15
16

17
18 In line with Wong, & Hodson (2009) and based on our study, we argue that in upper
19 secondary schools, science students should carry out some predictive and reflective modelling
20 activities, have peer reflection on experimental data in relation to models, carry out activities
21 related to scientific knowledge development, use induction and carry out activities related to
22 the practices (Hsu, van Eijck, & Roth, 2010) as well as motives of scientific researchers.
23
24
25
26
27
28
29

30 Appendix: The student questionnaire with Part I, some examples of Part II and Part III

31 Part I : Discipline-specific content knowledge

- 32
33 1. What is a ligand?
34 2. What is a receptor?
35 3. Describe in brief how cells communicate.
36 4. What is a histamine H₁-receptor?
37 5. What does a histamine H₁-receptor set in motion inside a cell?
38 6. What is the function of a blood-brain-barrier?
39 7. Explain the working of a medicine on cellular level.
40 8. What is a 'spacer'?
41 9. How do you know whether a synthesised ligand is not a mixture anymore?
42 10. Explain how the bonding activity of the ligand is measured.
43
44
45
46
47
48

49 Part II: Interest in scientific research; some examples

50 1. I like to learn how to do scientific research

- 51
52 0 disagree
53 0 disagree a bit
54 0 agree a bit
55 0 agree
56
57
58
59
60

...

1
2
3 3. I like to do scientific research
4

5 0 disagree
6

7 0 disagree a bit
8

9 0 agree a bit
10

11 0 agree
12

13 ...
14

15 5. Doing scientific research is dull
16

17 0 agree
18

19 0 agree a bit
20

21 0 disagree a bit
22

23 0 disagree
24

25 ...
26

27 8. I wish we could do more investigative work in class
28

29 0 disagree
30

31 0 disagree a bit
32

33 0 agree a bit
34

35 0 agree
36

37 ...
38

39 11. I wish to have a scientific career
40

41 0 disagree
42

43 0 disagree a bit
44

45 0 agree a bit
46

47 0 agree
48
49
50

51 Part III : Knowledge about scientific investigation and NOS; some examples
52

53 1. Write down as many activities possible that you consider to be scientific investigation activities.
54

55 2. Does the development of scientific knowledge require experiments? Explain your answer. (VNOS-Form C;
56 question 3)

57 3. After scientists have developed a scientific theory (for example atomic theory, evolution theory), does the
58 theory ever change? Explain your answer. (VNOS-Form C; question 4)

59 4. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
60 (VNOS-Form C; question 5)

1
2
3 5. Do scientists use their creativity and imagination during their investigations? Explain your answer. (VNOS-
4 Form C; question 8)

5
6 6. Why do scientists use models?
7
8
9

10 **References**

11
12 Abd-El-Khalick, F. (2006). Over and again: college students' views of nature of science. In

13
14 L.B. Flick & N.G. Lederman (Eds.) Scientific inquiry and nature of science. Implications
15
16 for teaching, learning and teacher education (pp. 425). Springer, Dordrecht.
17

18
19 Barab, S.A., & Hay, K.E. (2001). Doing science at the elbows of experts: Issues related to the
20
21 science apprenticeships. *Journal of Research in Science Teaching*, 1, 70-102.
22
23

24
25 Bell, R., Blair, L., Crawford, B., & Lederman, N. (2003). Just do it? Impact of a science
26
27 apprenticeship program on high school students' understandings of the nature of science
28
29 and scientific inquiry. *Journal of Research in Science Teaching*, 40, 487-509.
30
31

32
33 Bennett, J., & Hogarth, S. (2009). Would You Want to Talk to a Scientist at a Party? High
34
35 school students' attitudes to school science and to science. *International Journal of Science*
36
37 *Education*, 31, 1975-1998.
38
39

40
41 Brown, A.L. & Campione, J.C. (1996). Psychological theory and the design of innovative
42
43 learning environments: on procedures, principles, and systems. In L. Schauble & R. Glaser
44
45 (Eds.) *Innovation in learning: New environments for education* (pp. 289-325). Mahwah,
46
47 NJ: Lawrence Erlbaum Associates, Inc.
48
49

50
51 Buxton, C.A. (2006). Creating contextually authentic science in a "low performing" urban
52
53 elementary school. *Journal of Research in Science Teaching*, 43,659-721.
54
55

56
57 Charney, J., Hmelo-Silver,C.E., Sofer,W., Neigeborn,L., Coletta, S., & Nemeroff,M. (2007).
58
59 Cognitive apprenticeship in science through immersion in laboratory practices.
60
International Journal of Science Education, 29, 195-213.

- 1
2
3 Cobb, P., & Yackel, E. (1996). Constructivism, emergent and sociocultural perspectives in the
4 context of developmental research. *Educational Psychologist*, 31, 175-190.
5
6
7
8
9 Cohen, L., & Manion, L. (1994). *Research methods in education* (pp. 233-251). London:
10 Routledge.
11
12
13 Crawford, B.A., Krajcik, J.S., & Marx, R.W. (1998). Elements in a community of learners in
14 a middle school science classroom. *Science Education*, 83, 701-723.
15
16
17
18 De Esch, I.J.P., Thurmond, R. L., Jongejan, A., & Leurs, R. (2005). The histamine H₄
19 receptor as a new therapeutic target for inflammation. *Pharmacological Science*, 26, 462-
20 469.
21
22
23
24
25 Driver, R., Asoko, H., Leach, J. Mortimer, E.F., & Scott, P. (1994). Constructing scientific
26 knowledge in the classroom. *Educational Researcher*, 23, 5-12.
27
28
29
30
31 Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*.
32 Buckingham, England: Open University Press.
33
34
35
36 Eilks, I. (2003). Co-operative curriculum development in a project of participatory action
37 research within chemical education: teachers' reflection. *Science Education International*,
38 14, 41-48.
39
40
41
42
43
44 Engle, R.A., & Conant, F.R. (2002). Guiding principles for fostering productive disciplinary
45 engagement: explaining an emergent argument in a community of learners classroom.
46
47
48
49
50
51 Ford, M.J., & Wargo, B.M. (2007). Routines, roles, and responsibilities for aligning scientific
52 and classroom practices. *Science Education*, 91, 133-157.
53
54
55
56
57 George, R. (2006). A cross-domain analysis of change in students' attitudes toward science
58 and attitudes about the utility of science knowledge. *International Journal of Science*
59
60
Education, 28, 571 - 589.

- 1
2
3 Gibson, H.L., & Chase, C. (2002). Longitudinal impact on an inquiry-based science program
4 on middle school students' attitudes toward science. *Science Education*, 86, 693-705.
5
6
7
8
9 Gilbert, J.K. (2004). Models and modelling: Routes to more authentic science education.
10
11 *International Journal of Science and Mathematics Education*, 2, 115-130.
12
13
14 Gyllenpalm, J., Wickman, P., & Holmgren, S. (2009). Teachers' Language on Scientific
15 Inquiry: Methods of teaching or methods of inquiry? *International Journal of Science*
16
17 *Education*, 32, 1151 - 1172.
18
19
20
21 Helms, J.V. (1998). Science and/in the community: context and goals in practical work.
22
23 *International Journal of Science Education*, 20, 643-653.
24
25
26
27 Hsu, P-L., Van Eijck, M., & Roth, W-M. (2010). Students' representations of scientific
28 practice during a science-internship: reflections from an activity-theoretic perspective.
29
30 *International Journal of Science Education*, 32, 1243-1266.
31
32
33
34 Janesick, V.J. (2000). The choreography of qualitative research design. In H.K. Denzin &
35 Y.S. Lincoln (Eds.), *Handbook of qualitative research* (pp.379-399). Thousand Oaks, CA:
36
37 Sage.
38
39
40
41 Jenkins, E., & Nelson, N. (2005). Important but not for me: students' attitudes towards
42 secondary school science in England. *Research in Science and Technological Education*,
43
44 23, 41-57.
45
46
47
48
49 Kass, H., & Macdonald, A.L. (1999). The learning contribution of student self-directed
50 building activity in science. *Science Education*, 83, 449-471
51
52
53
54 Keys, C.W., & Bryan, L.A. (2001). Co-constructing inquiry-based science with teachers:
55 essential research for lasting reform. *Journal of Research in Science Teaching*, 38, 631-
56
57 645.
58
59
60

- 1
2
3 Krajcik, J.S., Blumenfeld, P., Marx, R.W., Bass, K.M., Fredericks, J., & Solloway, E. (1998).
4
5 Middle school students' initial attempts at inquiry in project-based science classrooms.
6
7 *Journal of the Learning Sciences*, 7, 313-350.
8
9
- 10
11 Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*.
12
13 Cambridge: Cambridge University Press.
14
- 15
16 Lotter, C., Harwood, W.S., & Bonner, J.J. (2007). The influence of core teaching conceptions
17
18 on teachers' use of inquiry teaching practices. *Journal of Research in Science Teaching*,
19
20 44, 1318-1347.
21
22
- 23
24 Lunetta, V.N., Hofstein, A., & Clough, M.P. (2007). Learning and teaching in the school
25
26 science laboratory: An analysis of research, theory, and practice. In S.K. Abell & N.G.
27
28 Lederman (Eds.) *Handbook of research on science education* (pp. 393-441). Mahwah, NJ:
29
30 Lawrence Erlbaum.
31
32
- 33
34 Mayer, R. (2004). Teaching of subject matter. *Annual Review of Psychology*, 55, 715-744.
35
- 36
37 Millar, R., & Abrahams, I. (2009). Practical work: making it more effective. *School Science*
38
39 *Review*, 91, 59-64.
40
- 41
42 O'Neill, D.K., & Polman, J.L. (2004). Why educate "little scientist?" Examining the potential
43
44 o practice-based scientific literature. *Journal of Research in Science Teaching*, 41, 234-
45
46 266.
47
48
- 49
50 Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the
51
52 literature and its implications. *International Journal of Science Education*, 25, 1049-1079.
53
- 54
55 Pera, M. (1994). *The discourses of science* (p. ix). Chicago: University o Chicago Press.
56
- 57
58 Richmond, G., & Kurth, L.A. (1999). Moving from outside to inside: High school students'
59
60 use of apprenticeships as vehicles for entering the culture and practice of science. *Journal*
of Research in Science Teaching, 36, 677-697.

- 1
2
3 Ritchie, S.M., & Rigano, D.L. (1996). Laboratory apprenticeship through a student research
4 project. *Journal of Research in Science Teaching*, 33, 799-815.
5
6
7
8 Roth, W.-M. (1996). Knowledge diffusion in a grade 4-5 classroom during a unit of civil
9 engineering: an analysis of a classroom community in terms of its changing resources and
10 practices. *Cognition and Instruction*, 14,170-220.
11
12
13
14
15 Sadler, T.D., Burgin, S., McKinney, L., & Ponjuan, L. (2010). Learning science through
16 research apprenticeships: a critical review of the literature. *Journal of Research in Science*
17 *Teaching*, 47, 235-256.
18
19
20
21
22 Schwartz, R.S., Lederman, N.G., & Crawford, B.A. (2004). Developing views of nature of
23 science in an authentic context: An explicit approach to bridging the gap between nature
24 of science and scientific inquiry. *Science Education*, 88, 610-645.
25
26
27
28
29 Shulman, L.S., & Sherin, M.G. (2004). Fostering communities o teachers as learners:
30 Disciplinary perspectives. *Journal of Curriculum Studies*, 36, 135-140.
31
32
33
34 Schön, D.A. (1983). *The reflective practitioner. How professionals think in action*. New
35 York: Basic Books.
36
37
38
39 XX (2004).
40
41
42 XX (2010).
43
44 Wenger, E. (1998). *Communities of practice, learning, meaning and identity*. Cambridge:
45 Cambridge University Press.
46
47 Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: model-
48 based inquiry as a new paradigm of preference for school science investigations. *Science*
49 *Education*, 92, 941-967.
50
51
52
53 Wong, S.L., & Hodson, D. (2009). From the horse's mouth: What scientist say about
54 scientific investigation and scientific knowledge. *Science Education*, 93, 109-130.
55
56 Yacoubian, H.A., & BouJaoude, S. (2010). The effect of reflective discussions following
57 inquiry-based laboratory activities on students' views of nature of science. *Journal of*
58 *Research in Science Teaching*, 47, 1229-1252.
59
60
61 Yin, R. K. (1994). *Case studies research: design and methods* (pp. 18-77). London: Sage.

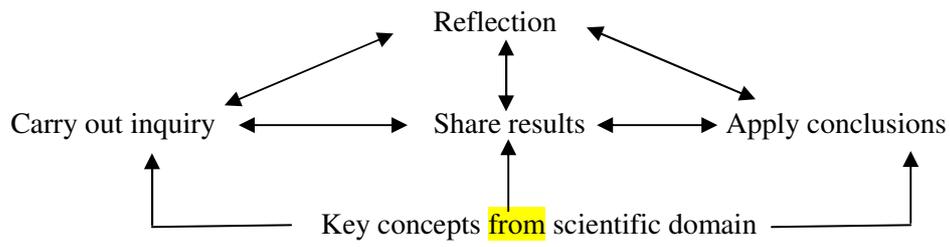


Figure 1. Basic student involvement in a community of learners (based on Brown & Campione, 1996).

For Peer Review Only

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Table 1. The main student activities in week 1-6 within the pharmacology research community

Research community	Main student activity
Week 1	Getting to know the research content and community
Week 2	Building, modelling and predicting the bonding capacity of ligands
Week 3	Synthesising a ligand
Week 4	Purifying and determining purity of the ligand
Week 5	Discussing the bonding capacities
Week 6	Preparing poster and presentation

Table 2. The participants' agreement on the achievement of each of the six design principles.

Participants in the research community	The six design principles					
	1	2	3	4	5	6
Students (n=10)	10	10	6	10	10	10
Teacher	1	1	1	1	1	1
Researchers (n=3)	2	3	3	3	2	3

For Peer Review Only

Table 3. The average student (n=10) scores in question 1-10 for week 1, week 6 and the total scores as well as the average change.

Question	Average score week 1 (n=10)	Average score week 6 (n=10)	Average change (n=10)
1	2.2	7.7	0.52
2	5.1	8.8	0.37
3	2.8	6.3	0.35
4	2.4	7.0	0.46
5	5.5	8.8	0.33
6	3.3	6.9	0.36
7	0	6.1	0.61
8	2.8	8.0	0.52
9	3.2	8.2	0.50
10	0	8.9	0.89
Total	2.73	7.67	4.94

Table 4. The average student (n=10) scores in statement 1-11 for week 1 and week 6. \checkmark means a positive change.

Statement	Average score week 1 (n=10)	Average score week 6 (n=10)	Positive change
1	3.6	3.7	\checkmark
2	3.1	3.1	
3	3.6	3.8	\checkmark
4	3.6	3.6	
5	3.5	3.8	\checkmark
6	3.1	3.1	
7	3.2	3.2	
8	3.5	3.9	\checkmark
9	3.4	3.4	
10	4.0	4.0	
11	3.6	3.9	\checkmark
Total	3.47	3.60	\checkmark

Table 5. Number of students who have naïve or informed views of NOS aspects in week 1 and week 6

NOS aspect (Question)	Week 1		Week 6	
	Naïve	Informed	Naïve	Informed
Requirement experiments (2)	10	-	3	7
Change in theory (3)	10	-	6	4
Difference theory and law (4)	10	-	9	1
Creativity and imagination (5)	10	-	-	10
Model (6)	10	-	-	10