Does integrated science education improve scientific literacy?

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Abstract

In Flanders, a choice has been made for the integrated school subject ‘Natural Sciences’, in ‘science for all’ secondary school trajectories, and for the three separate subjects biology, physics and chemistry, in trajectories for the future scientist and technician.

In the framework of the Flemish project ‘Practice-oriented reviews of research in subject matter teaching’, we have performed a study with the aim of investigating, on the basis of the existing literature, whether there is currently any scientific evidence that the integration of biology, chemistry and physics in the secondary school subject Natural Sciences improves student results for scientific literacy. The followed methodology is based on the general principles of the systematic review, but with the final goal of producing a text useful for teacher educators, teacher students and teachers, and not a technical review only readable by researchers in science education. The main result of this study is that there is currently no scientific evidence of the effectiveness of integration for scientific literacy. The main conclusion for practice is that integration alone does 'no magic'. This implies that intellectual freedom remains for teachers and teacher educators within the framework of the subject Natural Sciences on how to structure instruction. In the light of this, we stress the importance of educating future teachers to be aware of the current debate and to form their own opinion.

Keywords: science education, scientific literacy, integrated science

1. Introduction

1.1. Science for all and scientific literacy

When talking about education designed for all, a central issue is how science education should be organised to provide the necessary background, tools and attitudes to the future citizen, and at the same time to inspire and prepare the future scientist and technician for further studies and career (Eurydice, 2011).
‘Science for all’ is often associated with ‘scientific literacy,’ meaning, according to the PISA 2003 definition:

*the capacity to use scientific knowledge*

- to identify questions and
- to draw evidence-based conclusions

*in order to understand and help make decisions about the natural world and the changes made to it through human activity* (OECD, 2003).

Achievement of scientific literacy for all pupils is the major goal of a ‘Science for all’ curriculum. However, a science curriculum designed for the future scientist and technician should also achieve the scientific literacy of pupils, together with the suitable conceptual and technical depth needed for further scientific studies and career.

### 1.2. Structure and recent changes in the Flemish Science Curriculum

In the following, we give an overview of the science curriculum in Flemish schools (Eurydice). Flemish elementary school is for pupils in the age range 6-12 (6 years total) and Flemish secondary school for pupils in the age range 12-18 (6 years total).

In the last years, some changes have been implemented in the Flemish science curriculum. In particular, in some non-technical-scientific specialisations in secondary education, the separate scientific subjects chemistry, physics and biology have been replaced with one ‘integrated science’ subject.

#### 1.2.1. Primary Education

In elementary school, the so-called subject “World Orienteering” is an integration of science, history and geography. This subject approaches science by working with *specific examples*. The ‘amount’ of science pupils are exposed to in elementary school is in fact strongly dependent on the choices and the background of their teacher. The results of this approach to science in elementary school in Flanders are currently rather poor, according to the results of the Trends in International Mathematics and Science Study assessment 2011 (TIMSS & PIRLS International Study Center, 2011). The government is now trying to attack this problem. Introducing a specialized science and technology teacher at primary school level is an option.

#### 1.2.2. Secondary Education

In the first two years of secondary education, “Natural Sciences” as a subject for integrated science, has been introduced in 2010. The subject Natural Sciences includes, together with biological topics, some *elements of physics and chemistry*. Before, most pupils found only biology on their school programme.
In higher secondary education, the Flemish science curriculum has been structured according to the two possible trajectories: ‘science for all’ and ‘science for the future scientist and technician’.

In the 3rd and 4th year of secondary school, the integrated ‘science for all’ subject ‘natural sciences’ has been gradually introduced starting in 2007 in some specialisations in technical schools, instead of the three separate subjects physics, chemistry and biology. For some of these technical schools the total number of science classes per week has simultaneously been reduced from 3 to 2. Pupils in general schools and in some specialisations of technical schools still get the three separate subjects physics, chemistry and biology during 3rd and 4th year.

In the 5th and 6th year of secondary school, the integrated ‘science for all’ subject ‘natural sciences’ has been introduced in 2004, also in general schools, for pupils who do not explicitly choose to major in science or mathematics. The number of science classes per week has also in this case been reduced from 3 to 2.

This means that general school pupils who have followed the three separate subjects physics, chemistry and biology in 3rd and 4th year, but have not chosen for a science or mathematics specialisation in 5th and 6th year, go back to integrated science with very little science hours.

Secondary school pupils in Flanders score quite high in the PISA scientific literacy assessment (OECD, 2011).

1.3. Are the recent changes in the Flemish Science Curriculum evidence-based?

As described above, Flanders has recently changed its secondary school curriculum by replacing the separate subjects chemistry, physics and biology with one ‘integrated’ science subject for pupils who have chosen for non technical-scientific specialisations.

Underlying this decision, there is an implicit assumption that integrated instruction in science has a positive effect on scientific literacy, considered to be the major goal of a ‘science for all’ school trajectory. But is this assumption supported by facts?

These days, with the increasing pressure by our knowledge society to base any decision on scientific evidence, also in an educational context, we would expect that such curriculum changes implemented by the government, with consequences not only for pupils but also for teachers and for the general school organisation, were also supported by scientific evidence and were not based on ideology or current trends in pedagogy.

Considering that we are talking about curriculum changes concerning the improvement of scientific literacy, and that drawing conclusions based on scientific evidence is the central element of the already mentioned PISA 2003 definition of scientific literacy, it would be particularly striking if the decision to implement these changes had not been based on scientific evidence.
This reflection has inspired us to start a systematic search for scientific evidence of the effects of integrated instruction in science for the scientific literacy of pupils. More specifically, our review addresses the specific question:

**Is there scientific evidence that integration of biology, chemistry and physics to one school subject, natural sciences, improves student results for scientific literacy in secondary education?**

### 1.4. The project P-review

Our work has been performed in the framework of the Flemish project P-Review - Practice-oriented reviews of research in subject matter teaching, supported by School of Education, Association KU Leuven (Project P-review, School of Education - Association KU Leuven, 2013).

The goal of this project is to *bridge the gap between teachers and research in subject matter teaching*.

Research in subject matter teaching can only have an impact on the society if research results reach school teachers, who can then take them into account in their school practice. Unfortunately, teachers have little time to search for academic literature relevant for their teaching activity.

The project P-review makes relevant international research results accessible to Flemish teachers by producing 6 practice oriented reviews of research in subject matter teaching for the school subjects: natural sciences (review presented in this paper), history, biology in secondary education; ‘wereldoriëntatie’ (integration of science, history and geography), physical education, mother language in primary education.

The general project framework refers to the concept of systematic review. The material presented in the P-reviews must be collected by a *systematic procedure*, the details of which are presented in a *transparent* way in the text, so that the whole process is in principle *reproducible*. The research question addressed by the review must be chosen in advance, before knowing which relevant results are available in the literature. This implies that an ‘empty’ review is also meaningful in this approach, because it proves that for the chosen question no research results have been published yet and the problem is still open.

The P-reviews, in Dutch, are written in a style and with a terminology suitable for the target group of teachers, teacher students and teacher educators.

### 2. International debate on integration in (science) education

#### 2.1. Semantic confusion

We have been talking about the school subjects Natural Sciences in secondary school and World Orienteering in primary school as ‘integrated’, meaning that they are a form of *clustering* of different disciplines, such as biology, chemistry, physics, history, geography, in one school subject.
In the international literature, several authors point out that the integration of different subjects to one cluster subject can be organized in different ways. In fact, more than one classification exists for the possible integration structures, but a generally accepted definition of integration does not actually exist. Different authors, curriculum developers, policy makers, schools directors and teachers use the term integration with a different meaning. Therefore, semantic confusion can arise, in particular for teachers, who are normally not familiar with the academic literature on integration, when the terminology used in a certain context is not properly defined.

A simple and practice-oriented classification defines three categories or approaches to integration (Lederman, 1997), that we here apply to the case of Natural Sciences as a clustering of physics, chemistry and biology:

- The integrated approach is based on real-world problems. The three disciplines physics, chemistry and biology are not recognizable anymore. This approach can be compared to tomato soup, where the different ingredients are not visible anymore.

- The interdisciplinary approach uses the insights of the three separate disciplines, that are mentioned and recognizable, and applies them to the investigation of a natural science topic or problem. Basic knowledge in the separate disciplines is needed. This approach improves the understanding in the separate disciplines, by investigation of a topic, and can be compared to chicken-noodle soup. The different ingredients are recognizable and all contribute to the preparation, which, however, has also its identity as a whole.

- The thematic approach is similar to the integrated approach, but is organized around broad themes relevant for the society, like for instance energy, instead of starting from many real-world problems. The different disciplines are also not recognizable.

2.2. Arguments for and against integration

In the ongoing international debate on integration, we can identify a set of typical arguments for and against integrated/thematic instruction, see for instance (Czerniak, 2007).

The most common theoretical and ideological arguments in support of integrated instruction are:

- Reality is not organized in separate subjects.
- Pupils see the big picture instead of fragmented knowledge.
- Integrated instruction increases student motivation.
- Relevance: the content is organized around real-world problems and socially relevant themes.
- Connection with the pedagogical theory of social constructivism: more attention for relations among ideas.
The most common arguments against integrated instruction are:

- Almost no research results support the superiority of integrated instruction.
- There is no consistent definition of integrated instruction.
- Practical problems in the school practice arise...
- ... together with problems in the education and training of teachers!

The philosophical origin of the discussion on integration in (science) education can be found in the way a person experiences the existence of (scientific) disciplines. For some persons academic disciplines like biology, chemistry and physics are very powerful ways to organise and extend our knowledge in research. For others, academic disciplines are an artificial division with an historical origin, whose meaning is nowadays very limited (Czerniak, 2007).

3. Relevant empirical studies

Our systematic search for scientific evidence of the effects of integration of biology, chemistry and physics on the student results for scientific literacy, has brought us to the conclusion that surprisingly few empirical studies have been published on the subject. This is in striking contrast to the huge amount of literature on the topic, mostly providing arguments based on philosophical or ideological assumptions.

We have identified only two empirical studies relevant for our research question. These are Swedish studies based on the PISA results of 2003 with 1867 participating pupils (Åström, Integrated and subject specific. An empirical exploration in Swedish compulsory schools, 2007), and of 2006 with 4140 participating pupils (Åström, Defining integrated science education and putting it to test, 2008).

It is important to stress here that the PISA assessment for science is designed to test scientific literacy and not scientific knowledge and technical skills.

The authors have first determined which schools had followed an integrated, mixed or traditional curriculum in science. The statistical correlation between this information and the results of the corresponding pupils in the PISA-tests has been studied, together with the influence of other parameters such as gender, socio-economical status of the family and the language spoken at home.

1 The databases ERIC and Google Scholar have been used. For the chosen list of search terms they gave the same results. Only search terms in English have been used. A complete description of the followed systematic search procedure, including the list of search terms and excluded terms, can be found in the Appendix of our review (Project P-review, School of Education - Association KU Leuven. (2013). P-reviews - Onderzoek koppelen aan je vak. Retrieved from http://www.p-reviews.be/). To give some examples, the combination of 'integrated' with 'science education' in the title has been searched for, the terms "efficiency", "efficient", "effectiveness", "effective", in combination with "integrated" and "science" and "education" or "curriculum" or "curricula" have also been searched for in the title. Terms like 'undergraduate', 'university' and 'engineering' have been excluded because the review is about science education in secondary school. Relevant works cited by the articles found by systematic search have also been included.
The very special situation in Swedish schools in those years have made this study possible. Swedish schools could choose to follow an integrated, mixed or traditional, i.e. with separate subjects, science curriculum. The way final grade(s) for science were given, one grade or three, could be used as a cross-check of the declared school choice. In Flanders a similar study would not be possible, since schools cannot choose.

4. Results of the systematic literature search

The results of the two PISA-based studies differ. The first study, based on the PISA 2003 data, finds no difference in student achievement among different science curricula. The second study, based on the PISA 2006 data, finds a small difference in the student achievement among different curricula, but only for girls, and partly correlated to differences in socio-economical situation and home language.

To summarize, only two extensive quantitative studies have been found. They do not agree, since the second study sees a small statistically significant difference, only for girls, while the first one sees no difference.

It is therefore not possible to conclude, based on the currently existing empirical studies, that integration in science has an effect on student achievement for scientific literacy.

If we look back at the question addressed by our review, namely ‘is there scientific evidence that integration of biology, chemistry and physics in the subject natural sciences improves student results for scientific literacy?’, we see that the answer obtained in the framework of our systematic review is ‘No’. Therefore, offering an integrated subject natural sciences instead of the three separate subjects physics, chemistry and biology to pupils, does not automatically improve their scientific literacy.

This of course does not mean that integration in science education is ‘bad’. A teacher who believes in the integrated approach and who can work well in an integrated, thematic or interdisciplinary way in the class, has still all the rights to do it.

The result of the PISA 2006 based study, revealing a gender-based effect, is very interesting and deserves further investigation. This result is maybe not so surprising, though, considering that context-based approaches in science are well-known to have a positive effect on motivation and results for girls, see for instance the case of physics (Murphy, 2006). It is possible that teachers working in an integrated way in the classroom have given more attention to contexts than in the often more abstract or technically oriented traditional approach with three different subjects.

Another interesting consideration is related to the general discussion around performance vs. motivation in education.

The focus of our review is the effect of integration on student’s results in scientific literacy and not on the student motivation. An increase of student motivation is
however often mentioned in the literature as a positive effect of integration (Czerniak, 2007).
This stimulates a reflection on the meaning of the term ‘motivation’ and leads us to another example of semantic confusion in education. In fact, a classification of the different degrees of motivation can be found in the literature (Abrahams, 2010). The lowest one is *situational interest*, meaning that the pupil or student likes a certain activity more than other activities in the class, but with *no durable effects* after the end of the class. Therefore, situational interest has no effect on the learning process and on student achievement, but only on the atmosphere in the class.
The highest level of motivation arises when a student is engaged with the subject and is willing to make more efforts. In this case, motivation does lead to an improvement of the student performance. The fact that no evidence has been found of the effects of integration on the student performance implies the kind of motivation associated with integration is a form of situational interest.

5. Implications and suggestions for teacher education

The debate around integration in science education is currently of ideological and philosophical nature and not based on results of empirical research studies. This lack of scientific evidence for the effectiveness of integration implies *intellectual freedom* for teachers and teacher educators on how to give the subject natural sciences. Multidisciplinary, interdisciplinary, thematic or integrated instruction are all possible options, among which the teacher should be free to choose.

Since freedom remains for teachers to choose among different forms of clustered instruction in science, teacher education in science should also educate future teachers to make their *own choices* for their school practice in science education, by making them aware of the international debate concerning integration in science education and by stimulating them to develop their *own opinion* about it.

We are aware that some colleagues consider this kind of issues too philosophical for our students. We often hear that teacher students need clear instructions and should only be *trained* to execute a certain set of practical tasks in a professional way. However, the ‘tasks’ teachers are supposed to execute, and the set of topics they will have to present to their pupils in the classroom, will change several times during their teaching career.

In the following, we would like to give some suggestions on how a teacher educator could integrate the discussion on science integration in the teacher training. In the framework of a subject matter teaching course, of student projects or of a bachelor thesis, it is possible to let students explore the different possibilities for integration in the subject natural sciences. The different categories and levels of integration can be presented during the lectures. Several practice-oriented exercises for teacher students are possible based on these topics, for instance:

1. Browse several natural sciences textbooks and classify them according to the type and level of integration.
2. Discuss in groups the positive and negative aspects of integration. The issues raised by the different groups can be summarized and compared with what mentioned in the literature, see for instance (Czerniak, 2007).

3. What could be good topics for working in an integrated way in the science class? The topics found by the students can be compared with the official list of topics for the subject natural sciences.

This way of working with teacher students also automatically exposes them to research in science education.

Another possible discussion and reflection topic for science teacher students is the existence and role of the subject natural sciences in the general school curriculum. Students can for instance analyze the structure of science education in their country and discuss this in the context of the international debate on integration in science education.

In Flanders, teacher students who specialize in one of the three scientific subjects physics, chemistry or biology, are automatically allowed to teach the integrated subject natural sciences. Without considering the problems these students face, due to the lack of specific knowledge and possibly also a lack of interest in the other scientific subjects, one should consider that a ‘science for all’ integrated subject has a different goal, namely achieving the scientific literacy of all pupils.

But do science teacher students know what scientific literacy means? And do they know how they can work in the class to achieve it?

We think it is definitely possible and relevant to discuss scientific literacy with science teacher students. Some suggestions are: discussing the PISA definition(s) of scientific literacy during the lectures, letting students solve PISA sample questions in teams and let them reflect on these questions: why is this question actually a test of scientific literacy? PISA sample questions are freely available on the internet (OECD).

6. Summary and reflection for teacher education practice

The scientific conclusion of our review is that there is currently no empirical evidence that the integration of biology, chemistry and physics in one school subject, natural sciences, has any effect on student results for scientific literacy in secondary education.

Our practice-oriented conclusion, meant for teachers, future teachers and teacher educators, is that intellectual freedom remains for the teacher and teacher educator on how to approach the clustering of physics, chemistry and biology in one school subject. Multidisciplinary, interdisciplinary, integrated or thematic approach are all possible and the teacher should make an informed choice for its own school practice.

We would like to conclude with a message for (future) science teachers:

- Be aware of the ongoing debate on integration in science education.
- Form your own opinion on integration.
- Choose with this in mind among the textbooks for natural sciences and for your own class practice.
- Contextualising has a well-known positive effect on the motivation of girls, and you can do this in the subject natural sciences as well as in the separate subjects physics, chemistry and biology.
- The world of scientific research becomes more interdisciplinary with fields like nanoscience and nanotechnology: try to open this fascinating world for your pupils.
- Participate to scientific studies on integration and interdisciplinarity in science education with your class when this possibility is offered to you, even if this might be slightly inconvenient for your class practice.
Bibliography


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