Transformation of the Science Curriculum in Iceland

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PhD Thesis

UNIVERSITY OF ICELAND

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ABSTRACT

This doctoral thesis is primarily based on a compilation of research articles on the transformation of the science curriculum in Icelandic compulsory schools from 1960 to 2010.

The problem addressed in the thesis is the transformation of the science curriculum. It embodies the proposition that science education 'transforms' constantly, entailing constant conjunction and deliberation between distinct ideologies and curriculum models. The idea of 'transformation' indicates that the science curriculum evolves and reflects a state of perpetual flux rather than fixity.

Thus it was assumed that not only the official curriculum reflected constant changes; it also implied constant evolvement, ongoing and indivisible, of the implemented curriculum. Concepts from language studies, 'diachrony' and 'synchrony', were borrowed for further elaboration, where diachrony implies studying changes of the science curriculum over time and synchrony means studying its operation concurrently in various contexts. Thus the study sought answers to the following questions: What characterised the transformation of the science curriculum for Icelandic compulsory schools in force from 1960 to 2010:
a) from a diachronic perspective? b) from a synchronic perspective?

The thesis comprises three sets of research data and findings, first three articles based largely on documentary analysis about the transformation of the science curriculum, secondly two articles based on interviews and on-site observations with science teachers, thirdly practitioner-researcher data.

The findings imply that natural science, as a curricular field, proves to be dynamic in nature. Transient ideologies, traditions and curriculum models seem to mix regarding both policy and practice. Furthermore, the science curriculum appears increasingly as a 'crowded place', where new ideas and information have an easy access, but prior ideas and systems tend to remain and amalgamate with new ones, resulting in a curriculum that transforms into a 'kaleidoscopic quilt'. Practitioners, especially teachers, seem poorly prepared to deal with such complex conditions, resulting in 'particularistic' practices, where each school develops its own specific way of organising science learning and teaching, occasionally resulting in a null curriculum.

ÁGRIP

Þessi doktorsritgerð er skrifuð á ensku. Hún er í meginatriðum byggð á fimm greinum, sem fjalla um rannsóknir á námskrá í náttúruvísindum fyrir skyldunám á Íslandi yfir 50 ára tímabil frá 1960 til 2010.

Rannsóknarviðfangsefnið var þróun og umbreyting námskrár í náttúruvísindum. Hugmyndin um stöðugar umbreytingar (transformation) gefur til kynna að námskráin í náttúruvísindum taki látlausum eðlisbreytingum hvað varðar inntak og form; stöðugleiki virðist lítt sjáanlegur þegar þetta svið á í hlut.

Í rannsókninni var því gert ráð fyrir að bæði opinbera námskráin (intended curriculum) og virka námskráin (enacted curriculum) tækju stöðugum breytingum. Litið var á látlausa umsköpun námskrárinnar sem órofið ferli. Til að skýra þá hugmynd nánar var stuðst við tvö hugtök af sviði málvísinda, 'diachronie' og 'synchronie'. Það fyrra vísaði til samfelldrar þróunar yfir tiltekið tímabil, það síðara til stöðunnar á ákveðnum tíma með áherslu á „svæðið" milli stefnumótunar og framkvæmdar. Þannig var leitað svara við eftirfarandi meginspurningu: Hvað einkenndi umbreytingar námskrár í náttúruvísindum á Íslandi frá 1960 til 2010: a) Frá „díakrónísku" sjónarhorni? b) Frá „synkrónísku" sjónarhorni?

Helstu niðurstöður birtust í fimm tímaritsgreinum, þremur um greiningu ritaðra texta frá tímabilinu 1960 til 2010 og tveimur um vettvangsathuganir og viðtöl við kennara í náttúruvísindum. Enn fremur var stuðst við gögn sem tengdust starfi og rannsóknum höfundar (practitioner-researcher data).

Niðurstöður renna stoðum undir þá skoðun að náttúruvísindi sem svið í almennum námskrám reynist í eðli sínu kvik og síbreytileg hvað varðar hugmyndir, hefðir, inntak og skipulag. Enn fremur gefa þær til kynna að námskráin virðist orðin þéttskipuð; nýtt efni og nýjar hugmyndir virðast eiga auðveldan aðgang þar inn; eldri hugmyndir halda rótfestu en blandast þeim nýju að einhverju marki, svo námskráin fær á sig mynd síbreytilegs bútasaums (sbr. kaleidoscopic quilt). Kennarar virðast illa í stakk búnir að mæta þessum flóknu aðstæðum sem leiðir til þess að sérstaða skóla fer vaxandi hvað varðar nám og kennslu í náttúruvísindum og svonefnd núllnámskrá gerir vart við sig.

LIST OF PAPERS

The thesis is based upon the following papers, referred to by their Roman numerals

I. ***A perspective on the intended science curriculum in Iceland and its 'transformation' over a period of 50 years***
Þórólfsson, M., Finnbogason, G. E. & Macdonald, M. A.
International Journal of Science Education 2012, *34*(17), 2641-2665

II. ***'Transformation' of the science curriculum***
Þórólfsson, M.
Research in Social Science (Rannsóknir í Félagsvísindum) 2009, *X*, 701–714

III. ***'Transformation' of the intended science curriculum. A tension between instrumental and liberal purposes***
Þórólfsson, M. & Lárusson, E.
Research in Social Science (Rannsóknir í Félagsvísindum) 2010, *XI*, 205–213

IV. ***Views of five teachers in compulsory schools on the learning and teaching in science*** **[Published in Icelandic as:** ***Sýn fimm grunnskólakennara á nám og kennslu í náttúruvísindum*****]**
Þórólfsson, M., Macdonald, M. A., & Lárusson, E.
Journal of Educational Research (Tímarit um menntarannsóknir) 2007, *4*, 83–100

V. ***Learning science with ICT*** **[Published in Icelandic as:** ***Náttúrufræðinám með stuðningi upplýsinga- og samskiptatækni]***
Þórólfsson, M., Macdonald, M. A., & Lárusson, E.
Journal of Educational Research (Tímarit um menntarannsóknir), 2009, *6*, 85–106

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Finally, I want to thank my family for their understanding and support, especially my wife Rósa, who has patiently inspired me and read my texts and discussed them with me from the beginning of this work.

TERMS AND ABBREVIATIONS

Anachrony – A term used in this text to denote a discrepancy regarding order in which curricular ideas or ideologies appear in the data (See **Diachrony** and **Synchrony**).

CK – Content Knowledge. Shulman (1986; 1987) argued that science teacher knowledge should comprise several categories of knowledge, where CK, PCK and PK were of central importance.

CPD – Continuous professional development.

CPF - Computer Practice Framework, a model developed by Peter Twining (2002) for analysing the use of information and communication technology in science education (cf Article V).

Curriculum ideology – In this thesis written curriculum texts were analysed with respect to transient curriculum ideologies (Schiro, 2008), such as learner-centred, scholar academic, social efficiency, and social reconstructivist.

DED – Department of Educational Development in operation under the auspices of the Ministry of Education 1985 to 1990.

DER – Department of Educational Research in operation under the auspices of the Ministry of Education 1966 to 1984.

Diachrony – A term used to denote studying changes of the science curriculum over time (see anachrony and synchrony).

ECS – East Comprehensive School, a model school in science, among sources of data.

Flux or fixity – Terms used to iterate that synchrony means that the science curriculum does not only change over time; at any one time we will find flux, not fixity, because it is dynamic and varies at any one time, for example from one school to another.

Historical consciousness – The idea of pursuing all elements and manifestations of the curriculum longitudinally from the past into the present and from there into the future by ‘construing the past, comprehending the present and encountering and motivating the future’.

ICT – Information and communication technology.

Implemented curriculum – The actual process of learning and teaching in schools, the enacted curriculum.

Intended curriculum – The formal written curriculum, most often nationally published, with rationale, and prescribed aims and contents.

IR, Intentions and Reality – A research project on science education conducted in 2005 – 2007, among sources of data.

ISCIQ - Icelandic Science Curriculum Implementation Questionnaire – A questionnaire developed to gather quantitative data about certain factors in school science (See **SCIQ**)

ITT – Initial teacher training.

Mathematical time or pure time – The transformation of the science curriculum conceived as measureable durations, divisible into units and intervals (cf **real duration**).

ME – Ministry of Education.

MEC – Ministry of Education and Culture.

MESC – Ministry of Education, Science and Culture.

Model school project – A project where certain core schools in Reykjavík (i. *móðurskólar*) were subsidized to build exemplary learning programs in school science in 1999 to 2002, and promote mutual partnerships among schools and share effective practices with other compulsory schools in Reykjavík.

Nature studies – In this thesis the Icelandic word 'náttúrufræði' is explained as 'nature studies', sometimes erronously interpreted as the study of living natural phenomena.

New science – Referred to as the 'new science wave' or the curriculum reform that affected world-wide science education in the 1960s.

OECD PISA – An international study aiming to evaluate general literacy, mathematical literacy, and scientific literacy worldwide every three years.

PCK – Pedagogical content knowledge, see CK above and Shulman's arguments about science teacher knowledge.

PK – Pedagogical knowledge, see CK and PCK above.

Pracademic – Practitioner and an academic.

Practitioner-researcher data – Sources of data are partly found in the researcher's own area of practice.

RCE – Reykjavík Centre of Education, files from RCE are sources of data.

Real duration - The transformation of the science curriculum conceived as real duration, ongoing and indivisible, rather than being of measureable durations, divisible into units and intervals (See **mathematical time**).

Scientific literacy and **science literacy** – The term scientific literacy refers to the ability to understand and discuss scientific matters in relation to personal, social and global contexts; science literacy refers to the ability to talk, write and read about concepts and ideas in the sciences.

SCIQ, Science Curriculum Implementation Questionnaire – A questionnaire developed to gather teacher perceptions of quantitative data about certain factors in school science.

SES – Suburban Elementary School, a model school in science, among sources of data.

Synchrony – A term used to denote studying the operation of the curriculum as it occurs simultaneously in various contexts (See **Anachrony** and **Diachrony**).

TALIS – Teaching and Learning International Survey (TALIS), an international survey on the conditions of teaching and learning conducted by OECD.

TIMSS – Third International Mathematics and Science Survey conducted by IEA.

Transient – Refers to the fact that curriculum ideologies appear as transient in the findings; they seem to remain in place over a brief period of time, then they decay but never disappear completely.

WES – West Elementary School, a model school in science, among sources of data.

CHAPTER 1

THE THESIS AND ITS CONTEXT

Systems of schooling tend to remain remarkably traditional compared with other social systems (Elmore, 2008; Elmore & McLaughlin, 1988; Fullan, 2001; Goodlad & Klein, 1974; Snyder, Bolin & Zumwalt, 1992; Tyack &Cuban, 1995). Nevertheless, they do *transform* in various ways. Reform or change of a school curriculum, one way or the other, is a 'steady work' at least with respect to discourse:

> … the work is steady, because there is a limitless supply of new ideas for how schools should be changed and no shortage of political and social pressure to force those ideas onto the political agenda … To say that educational reform has had little effect on teaching and learning in schools, however, is not to say that reform has had no effects. (Elmore & McLaughlin, 1988, p. 3)

If these ideas are transferred into an Icelandic educational context, it can be argued that the effects of educational reform have been negligible historically regarding teaching and learning in classrooms, albeit the system as a whole transforms steadily. The title of this dissertation, *Transformation of the Science Curriculum in Iceland*, implies that the science curriculum as well as the school system as a whole transforms steadily. This transformation may appear as incremental, progressively going on at all times, everywhere, or as reform movements, miniature revolutions or 'policy churns' meant to overthrow the current state of the system. As indicated in Article II, it has been argued that natural science is the most revised of established curricular areas, 'at least in respect of proposals for reform' as Donnelly (2006) phrased it. The perpetual impulses for curricular changes in science education have even been depicted as religious correctness (Article III): 'The view that the science curriculum must change has become so common as to be an orthodoxy' (Donnelly & Jenkins, 2001, p. 2).

1.1. The Research Problem and Nature of the Research

The problem addressed in this doctoral study is the *transformation of the science curriculum* in the Icelandic compulsory school system and ideologies and philosophical views affecting its evolution. It embodies the proposition that the science curriculum 'transforms' constantly, implying that in effect it reflects a state of perpetual flux rather than fixity. Thus it is assumed that not only the official curriculum as presented in official documents reflects changes from one point of time to another; it also implies constant and real evolvement, ongoing and indivisible, of the implemented curriculum as well as the intended curriculum. Examining what characterises this evolvement requires taking into account *the diachronic dimension* and *the synchronic dimension*. In this thesis the diachronic perspective denotes how the curriculum has evolved over a period of fifty years, 1960 to 2010, but the synchronic perspective denotes how the curriculum operates simultaneously in selected contexts, namely how the official curriculum 1999 operated in various contexts from the events leading up to its adoption in the mid-1990s until its aftermath in the 2000s.

This requires an analysis of the curriculum with respect to transient ideologies based upon and theories related to curriculum development. The term 'transient' reflects the idea that particular models for curriculum development underlie educational texts and discourse over specific periods of time and then their effects diminish but are still evident as the curriculum transforms over time; ideologies affecting curriculum development supposedly wax and wane, but they also intertwine. Thus it is presumed that the transformation of the science curriculum entails constant conjunction and deliberation between distinct views on what scientific knowledge and skills are of most worth, and what kind of learning experiences and organization of learning environments are considered appropriate. Special attention is directed at the relationship between intentions as specified in curriculum documents (*the intended curriculum*) and the actual process of teaching and learning (*the curriculum-in-action*) in that respect (cf. van den Akker, 2010; Macdonald, Pálsdóttir & Stefánsson, 2008).

The thesis draws on a compilation of five published articles and other sources, where the science curriculum in Iceland was studied as it evolved over time and as it has appeared at a specific point of time. Normally the transformation of the science curriculum would presumably be comprehended as measureable durations, divisible into time intervals. But in this thesis it is rather conceived of as real duration, ongoing and indivisible (cf. Bergson, 1946). Two concepts from the study of linguistic changes were borrowed for further elaboration. The two concepts, 'diachrony' and 'synchrony', originated in Greek, where dia means 'through' or 'along with', and syn means 'concomitant' or 'together with' and chronos refers to time. Accordingly diachrony implies studying changes of the science curriculum over time and synchrony means studying its operation as it occurs simultaneously in various contexts.

The thesis seeks answers to the following questions:

- *What characterised the transformation of the science curriculum for Icelandic compulsory schools in force from 1960 to 2010?*
    - *From a diachronic perspective?*
    - *From a synchronic perspective?*

1.1.1 The Thesis and its Sources

In addition to historical data reflecting the transformation of the science curriculum, the overall thesis also builds on recent data collected by the author, either by himself or in collaboration with researchers in the School of Education at the University of Iceland. Both primary and secondary sources were used. Primary sources are written documents such as reports, memos, and interviews (oral history). Secondary sources are to a certain extent part of the literature review, like books and articles, that is, sources of data where the subjects involved relied on data from other sources. In this research it is not always easy to discern the difference between a primary and a secondary source. The same document or part of it, may be defined as a primary source from a certain point of view and a secondary source from another point of view. The rationale of the intended curriculum can for example be viewed as both, because it may in part stand on its own but in part it relies on other sources, such as ideologies obtained from the literature on science education or curriculum theory. Furthermore it is assumed that historical analysis and literature review inevitably overlap.

The thesis comprises three sets of research findings. First, there are three articles written in English based largely on documentary analysis about the ***transformation of the science curriculum*** (Articles I-III). Second, there are two articles originally written in Icelandic based on interviews and on-site observations with ***five distinctive science teachers*** on their professional ideas about science learning and teaching and use of ICT with respect to the 1999 curriculum (Articles IV and V). Third, there are findings based on my work as a practitioner and a researcher during the preliminary period for the 1999 national curriculum and while it was in effect (Appendices III and IV).

1.1.2 Research Perspectives

Theoretically this thesis draws upon four main perspectives, the complexity of educational data, understanding causal relationships in historical research, relevance of different forms of data, and historical consciousness

First, since the study concerns collection of educational data, to a considerable extent from secondary sources, the research is complicated in nature; it actually is what Berliner (2002) has been labeled as 'hard-to-do' science, since comprehending regularities in educational contexts is considered harder than in other scientific fields, for example, in so-called ‘hard sciences’ such as physics. Educational research like this study is complex in nature due to unlimited networks of ideas and discourse, and ‘ubiquity of interactions, power of contexts [and the fact that the] half-life of educational findings is short’ (Berliner, 2002, p. 20). By short half-life of findings Berliner maintained that educational data at one point of time prove to be of little use at later times because of changes that invalidate the older data or render it irrelevant.

Second, studying the transformation of the science curriculum involves to a certain degree identifying and evaluating causal relationships as in historical research: ‘Causal inference in historical research is the process of reaching the conclusion that one set of events brought about, directly or indirectly, a subsequent set of events’ (Gall, Borg & Gall, 1996). Obviously such studies do not apply to traditional scientific research methods, dealing with objective and measurable phenomena. Historical research where texts are analysed and relationships are interpreted has in effect little to do with positivist philosophy, which relies mainly on quantitative, empirical evidence. Historical research relies on the epistemological assumption that historical contexts and social relationships are critical in providing an understanding of the phenomena being investigated; curriculum ideologies and theories ‘reach far down into our personal, social, and cultural depths.’ (Walker & Soltis, 2009). Consequently all elements of the transformation of the curriculum are taken into consideration, observed as relevant parts of an ongoing duration where historical consciousness is the guiding light, implying that all elements must be ‘pursued longitudinally from the past into the present and from there into the future’ (cf. Goodson, 2005, p. 206). Accordingly events or phenomena occurring at a certain point of time in the past should help to illuminate, or even explicate, phenomena occurring in the present or in the future. The bottomline is that events and ideas related to education such as the transformation of the science curriculum do not take place in a vacuum; they are inevitably intertwined and parts of educational philosophy and societal phenomena as greater wholes (cf. Cohen & Manion, 1994). Thus causal inferences in this study cannot be built on statistics as traditionally practiced in quantitative research. This incurs the danger of producing less credible evidence than empirical research does where knowledge is gained by means of direct observation or experience. It also incurs the danger of oversimplying what the findings indicate. But since causes of events and ideas are complex and manifold the methods of inquiry need to be both interpretive and objective in nature; they also need to be scientific, systematic and rigorous, which was an important focus in this study.

Third, this kind of thesis does not easily align with the discrimination between quantitative and qualitative traditions of research, so it is irrelevant to declare it as either or. It is a historical analysis of the science curriculum in Iceland featuring a systematic gathering and critical analysis of documents, records, and oral recordings of personal memoirs and views from individuals that have been part of the transformation of the science curriculum. To a degree it is claimed to rely remotely upon a postpositivist epistemology, insisting that phenomena can be studied objectively to a certain extent. But the study takes into account that the experience, knowledge and values of both researchers and subjects influence what is observed, and thus it relies mainly upon a constructivist epistemological perspective, viewing knowledge as constructed and interpreted rather than being discovered externally. It connotes the idea of multiple and complex realities, and thus excluding one single true knowledge about the phenomena being examined. Otherwise stated: When the transformation of the science curriculum is studied historically it may prove helpful to divide its evolution into relevant intervals, and thus examining it objectively with respect to the evolution of other phenomena such as political or social trends, which invokes a postpositivist view. Examining the transformation of the curriculum as a real duration on the other hand, a continuous flow of reality layered with multiple meanings, builds on the constructivist view. This study relies primarily on this latter perspective.

Fourth, a central conception in this thesis is ‘historical consciousness’, thus time and historical change are considered as fundamental. According to Rury (2006) the misconception of seeing historical research as simply a chronicle of the past is widespread and also the impression that history is an objective discipline, ‘verifying the conditions under which events occurred.’ (p. 324). Actually, I consider chronology important for this study, and likewise verifying conditions and context from the past. But an urgent need for interpretation and hermeneutics is inevitable in such a study; studying the past in relation to the present is certainly more complex than simply tracing a chronological ordering of events. The conception of time is an essential factor of this kind of historical analysis, whether it is conceived from a postpositivist perspective or a constructionist perspective. The French philosopher Henri Bergson’s (1946) demarcation between two forms of time, ‘mathematical time’ and ‘pure time’, clarifies this view. Mathematical time is a measurable duration, divisible into units or intervals, but it does not reflect the real flow of time as pure time does, because then it would have to be what Bergson termed ‘real duration, continuous and indivisible’. Furthermore Bergson argued that experience and intuition were more significant than rationalism and science for understanding reality. Ultimate reality is constantly changing, and according to Bergson intellect and intuition are two different ways to provide a unified knowledge of it.

1.1.3 Diachronic and Synchronic Dimensions

The Swiss scholar, Ferdinand de Saussure, proposed that studies of human language should account for its changes over time on the one hand and its status or cross-section at particular points of time on the other hand (Harris 2001; Widdowson, 1996). Changes over time were labeled as the *diachronic dimension*, and status at a particular time the *synchronic dimension*. But as Widdowson argues synchrony should not be confused with stability and the context will always be complex and multi-planed:

> Wherever you take a synchronic slice through language you will find not fixity, but flux. This is because language does not just change *over time*, but varies *at any one time*, and indeed this cannot be otherwise because the members of a community

which 'shares' a language will themselves be of different ages, will use language differently, and will have different communicative and communal uses for it.

(Widdowson, 1996, p. 22– 23)

It is my proposition that the science curriculum changes over time and varies at any one time in a similar fashion as applies for language. As a matter of fact this evolution of language and curriculum and in fact the evolution of any other comparable phenomenon is a natural fact (cf. Articles II og III). As notified before transformation of the curriculum suggests conditional meaning and relativity in this respect. It implies constant changes over time and 'not fixity, but flux' at any one time as goes for language development (Figure 1).

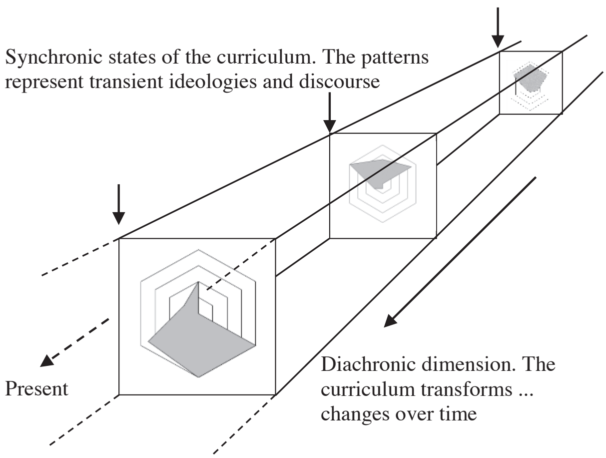

Figure 1. Studying the science curriculum accounts for changes over time (the *diachronic* dimension) and its status or cross-section at particular points of time (the *synchronic* dimension) which presumedly embodies 'flux' in a similar fashion as a languge system does. (Based on Widdowson, 1996)

Like Saussure and many others, the French philosopher Emmanuel Lévinas used the concepts of synchrony and diachrony, but to an extent differently. He used them to identify different modalities of time (Hutchens, 2004). According to Levinas *synchrony* applied to the single self striving to remember the past, perceive the present and predict the future. *Diachrony* applied to others introducing pasts and futures that the self could not remember or predict. And Levinas used the third concept, *anachrony*, to account for the pasts, presents and futures of all the others, whether dead, absent or unborn, in which the self could not share (Hutchens, 2004, p. 67).

The idea of conceiving time subjectively on the one hand as real duration, continuous and indivisible, and objectively on the other hand, as measurable duration of divisible events, illustrates the fundamental position regarding methodology applied in this study of the transformation of the science curriculum in Icelandic compulsory schools. I assume that there is a viable middle ground between the two perspectives although the study relies more on the latter. The notions that reality can be observed objectively on the one hand and that it can be observed subjectively on the other hand, both have their strengths.

Consequently the theoretical perspective of this thesis rests on the belief that there is a viable point of view in between which recognizes as valid the insights that both offer: There are facts about reality independent of human cognition, e.g. the contents of a curriculum. Humans interpret such facts in the context of social relationships, the curriculum is translated, or 'transformed', according to experiences, beliefs, meanings and professional theories.

Accordingly the science curriculum is studied as it evolves over time and as it appears at specific points of time. Synthesizing past, present and future transformations embodies a historical consciousness, which means that nobody can be isolated outside of the flow of real time, we are all participants in the flux of reality where we strive to 'construe the past, comprehend the present and encounter and motivate the future' (MESC, 2007b, p. 15)[1].

[1] Icelandic: '… að túlka fortíð, skilja nútíð og mæta og móta framtíð'.

1.2 Personal Perspectives

Since starting school about the time that the first official curriculum came into effect in 1960 I have been an active participant in the Icelandic public education system, mostly connected to science and mathematics education. Besides identifying myself as a keen and critically thinking learner in science and mathematics for half a century I have been involved in multiple projects related to school development, lower-secondary school teaching, professional development, and work for municipalities and national authorities. I received my B. Ed. and M. Ed. education in the Iceland University of Education with biology, mathematics, physics and geography as main areas of study. In my M. Ed. thesis, titled *Time and Space - Knowledge formation as a social construct* (i. *Tími og rúm - Þekkingarmyndun sem félagsleg hugsmíði*), I focused on epistemological issues related to the basic conceptions of time and space in science and mathematics education, and also in general contexts as human beings encounter these concepts in every-day settings through informal learning.

1.2.1 My Experience as a Compulsory School Pupil in the 1960s

Iceland is an island in the North Atlantic Ocean, easily perceived as an 'open book' for learning science, with its waterfalls, unstable weather, multiform seashores, volcanos, abundant wildlife, geothermal energy, miscellaneous power stations and lots of other approachable phenomena related to natural science and technology. The place of my youth was pervaded with such opportunities. I was brought up in *Seltjarnarnes*, a municipality which is geographically a suburb of Reykjavík, but was a peaceful rural community when I was brought up there during the 1950s and 1960s, with clusters of houses like small villages scattered over the small peninsula (i. *Nesið*) and in between them fishing farms with boats on both sides of the peninsula and farmhouses with cows, chicken, sheep and horses. My home was located close to a flourishing marsh area where you could find a large number of plants and migratory birds throughout the summer and during the winter it was covered with vast sheets of ice encircling the frozen tussocks and withered grass, all this an ideal opportunity to study seasonal transformations in nature as a consequence of the rotation of the earth on its axis and its movement around the sun. The ice was a popular scating rink. A short distance away from the marsh was the coastline where you could experience the rise and fall of sea levels caused by the gravitational forces between the earth, moon and the sun; and the sea shore was an exciting world of diverse marine organisms to explore. Not far away was a fish freezing plant, called *Ísbjörninn* (e. *The Polar Bear*), which was also an interesting place to explore with its freezers, fish processing engines, trucks, conveyer belts, cranes and carousels.

Close to the freezing plant was *Mýrarhúsaskóli*, the school that I attended from six to fifteen years of age. We learned the traditional subjects found in the national curriculum (ME, 1948; 1960) such as spelling, arithmetic, geography, history, english, danish and nature studies (i. *náttúrufræði*). Nature studies was taught and learned through textbooks with titles like botany, physiology, physics, zoology and nature study. Biology as a self-contained school subject did not enter the curriculum until the mid-seventies. I do not recall lessons labeled ‘science’ or ‘natural science’ (i. *vísindi* or *náttúruvísindi*) during my compulsory school attendance or any talk about science related to practical work promoting skills, techniques, methods or performance as scientific methods used to explore things or connect to conditions beyond the walls of the school house, such as the seashore, the wild life of the marsh or the fish processing activity. Although I have no recollection of particular lessons in nature studies that interested me specifically at that time, I do remember two interesting textbooks about physics, one named *Kennslubók í eðlisfræði handa unglinga- og gagnfræðaskólum* (e. *An instructional textbook in physics for lower-secondary schools*) (Bjarnason, 1956) and the other named *Hvers vegna – vegna þess* (e. *By what causes – on account of*) (Arnlaugsson 1956–1957). At that time I also remember having been interested in the series of books published by Time-Life in the mid 1960s, *Life Science Library,* which was translated into Icelandic in 1967 under the Icelandic title *Alfræðasafn AB* published by Almenna bókafélagið, where scientific phenomena were explained and discussed in a number of hardbound books of good quality, illustrated with sophisticated pictures, figures and diagrams.

During my attendance at *Gagnfræðaskóli Vesturbæjar*, a lower–secondary school where I took the national examination (i. *landspróf*), a preliminary examination for attending grammar school, I remember some specially designated teachers who taught physics, biology and geography with great enthusiasm and proficiency. Their narrations and discussion about natural concepts and phenomena motivated my interests in science learning and the textbooks interested me also, especially the ones on physics, *Eðlis- og efnafræði fyrir gagnfræðaskóla I & II* (e. *Physics and chemistry for lower–secondary schools I & II*), translated from Danish (Andersen & Norböll, 1967; 1968). There were interesting chapters about physical phenomena there, such as series and parallel circuits that interested me particularly, especially how parallel circuitry was employed in homes, so that each appliance had full voltage, and all the lights did not go out when one was turned off.

When entering secondary school, a grammar school in Reykjavík (i. *Menntaskólinn í Reykjavík*) in 1970 I selected natural sciences as a main course of study. This was the time when the unprecedented wave of ‘new science’, that had started in North America in the mid-1950s, reached the shores of Iceland. During my first year in grammar school we read an Icelandic translation of the American CHEM study, *Chemistry – An Experimental Science* (i. *Vísindi byggð á tilraunum*), where I certainly got acquainted with practical work, actually practical work as practiced among real scientists or in the authors’ own words: ‘… with emphasis upon the most enjoyable part of chemistry: experimentation.’ (CHEM study, 1963).

1.2.2 Development of the Educational System since the Second World War

In 1946 several acts regarding education came into effect in Iceland, together reflecting a conception of a holistic or integrated public educational system (Magnúss, 1946). During that time the population of Iceland was approximately 130 400 (Statistics Iceland, n.d.) with low population density, the inhabitants depending to a large extent on fishing and agriculture. The first formal national curriculum for compulsory education was issued in September 1960 when the population had grown to 173 900 and the population density had grown.

For two decades, from 1946 to 1966, stagnation had characterized the education system in Iceland (Kjartansson, 2008). But the reform movement that started with the establishment of a governmental agency in 1966, the *Department of Educational Research* (DER), began a swirl of ideas and reform efforts that reached every corner of the school system over the next 15 years. The economy of Iceland was evolving rapidly at this time and onwards, resulting in a highly developed manufacturing and service system (Statistics Iceland, 2011). Consequently the support for educational reform reflected a specific emphasis on cognitive, scientific and technical outcomes in education, especially in physics, chemistry and biology (ME, 1968; 1969). The Republic of Iceland was among the founder countries of OECD in 1961, which focused on the importance of education as an impetus for economic growth in the 1960s. The economic focus reflected the view that an advanced technological society needed scientifically educated subjects to sustain its status (Telhaug, 1990). But as explained in Article I the reform ideas emerging in the work of the DER in the 1960s and 1970s were by no means uniform in that sense; the emphasis on scientific and technical outcomes were challenged by other ideologies. As an example there was a tension between what was called a mechanical curriculum approach and an organic curriculum approach (Jóhannesson, 2008), reflecting what has also been called an instrumental approach on the one hand and a liberal approach on the other (Article II). The analysis of the official curriculum as described in Article I reflected this through the conceptions of a content-product approach on the one hand and a process-development approach on the other hand.

The Icelandic school system includes preschools for ages 18 months to 5 years, primary and lower secondary schools in a single structure (i. *grunnskóli*) for ages 6 to 15 and secondary schools for ages 16 to 19. According to law and tradition the official curriculum in Iceland has had the same status as regulations (cf. MEC, 1989) and the curriculum for compulsory subjects like science are determined centrally by national authorities. But, compared with other countries, Icelandic schools still prove to have had considerable autonomy in deciding on what to teach and how. According to the TALIS Survey (OECD, 2009) Iceland is among the highest scoring countries regarding teacher autonomy and decisions about course content and how it is taught (cf. Article I).

In 1996 there was a fundamental change in the management of compulsory schooling in Iceland. The management moved from central authorities, the ministry of education, to the municipalities, resulting in enhanced power and responsibility among the municipalities in policy making and curriculum development. At the same time (1995) a new law came into effect promoting more central inspection than before, and in 1999 a new national curriculum was issued covering almost one thousand pages of detailed aims and objectives (Article I). In Icelandic education this was introduced as a 'new' rationale for a 'new' century presented by the liberal conservatives that governed the Ministry of Education, Science and Culture (MESC) from 1991 to 2008, ' … the beginning of a new chapter in the history of education in Iceland' (MESC, 1999, p. 5). The message was that ' … clear objectives are a basic premise for school operations' (MESC, 2004, p. 24), appearing as a conclusive call for behaviouristic instruction. But the message of the 1999 curriculum also turned out to be that teachers should work according to constructivist ideas, emphasising 'science education as a process and a creative exercise rather than acquiring specifically defined knowledge and proficiencies' (MESC, 1999, p. 11). This jumble of ideologies appearing in the official curriculum at the turn of the last century proved to be an important theme in this thesis, conceived of as a symptom of flux.

1.2.3 Participation in 'Policy Churns'

From 1978 to 1997 I worked as a teacher and administrator in compulsory schools, where I participated in various projects, e.g. evaluation and curriculum development. In 1990-1993 I withdrew from teaching for three years to work as a consultant and leader of projects for the Ministry of Education and Culture and the Institute of Research in Education, mostly connected to evaluation, assessment and testing in science and mathematics. From 1997 to 2002 I worked as an educational advisor for the Reykjavík Centre of Education (RCE), mainly in the area of science and mathematics education. Among other projects I conducted a study on the status of physics and chemistry learning and teaching in Reykjavík (Þórólfsson & Birgisdóttir, 1998), took part in organising the work of model schools (i. *móðurskólar*) in science education and conducted educational programs for gifted children where science and mathematics were important areas of interest. Data from my work at the RCE was used to support answers to the research questions in this study (Appendix III).

I have also participated in committees and administrative assignments for the Association of Icelandic Mathematics Teachers and the Association of Icelandic Science Teachers, and alternatively as an advisor, specialist and committee member in various projects administered by the Ministry of Education and Culture (MEC), the Association of Local Authorities in Iceland, the Iceland University of Education, the University of Iceland and others. The projects concerned mainly curriculum development in general and program evaluation in mathematics and science and assessment as well as testing. Participation in the NORDLAB project 1999-2005 was an important experience where I coordinated the work of experts from energy companies, teachers, students and other educators in a project on energy education. The Icelandic part was about teaching and learning about the provision of energy, (Scandinavian: *Samhällets energiförsörjning*) (Icelandic: *Orka: Frá náttúru til neytenda*). Among innovations connected with the NORDLAB project students participated in conferences about energy and energy consumption with scientists and other specialists in the area of energy provision.

Looking back at my work I realize that, in spite of the fact that the ideas and intentions were noble and exciting, the major part of these efforts seem to have embodied what Richard Elmore (2008) portrayed as 'policy churns'. The activities comprised a swirl of ideas and reform efforts that were in fact fragmentary in essence, and vaguely synchronized with actual practice in schools, the traditional syntax of school work. In most cases, quick solutions were offered, officially meant to improve the quality of learning and teaching, but hardly ever resulting in long-term betterments, because old solutions were rapidly replaced with new ones that were in effect what has been called 'old wine in new bottles'. Actually I did not realise until later on how tangible my involvement in this 'farce' of policy churns had been from the very beginning of my career, first as a student teacher, then a novice in science teaching during the major reform era of the 1970s in Iceland, and later on as an explicit member of teams and committees striving to tailor 'ideas to an unstable political environment' as Richard F. Elmore (2008, p. 218) put it.

1.2.4 Historical Consciousness

During my second year as a lower-secondary school teacher by the end of the 1970s I was assigned to teach physics at the lower-secondary stage in a school in the Eastfjords of Iceland. This experience, along with many other events during my continuing career as a curriculum organiser and science educator, inspired my interest in studying the science curriculum in a historical context. The physics material taught in this Eastfjords school was labelled *Eðlis- og efnafræði 1 – 2* (*Physics and Chemistry 1 – 2*) (Ólafsson & Helgason, n.d.). The year was 1979 and it was near the endpoint of the 'new science' wave that had started in the USA and UK some 25 years earlier and these learning materials were sort of leftovers from that unprecedented macro-wave of curriculum reform.

Despite some innovative advantages and strengths such as more up-to-date contents than before, scientific validity and discovery-type learning methods with 'exciting' experiments, measuring, burning and pouring stuff into test tubes, beakers and boiling flasks, my students and I gradually realised that there was something wrong with this kind of learning. Me and my students were probably not prepared for this kind of work, indeed it did not make sense. When I looked back at those scenarios two decades later I decided that the abstract nature of the material must have been part of the problem. It was simply too difficult to comprehend because of its 'theoretical sophistication' as Paul DeHart Hurd remarked (cited in DeBoer 1991) about the 'new science' curriculum. Consequently it must have been too far for students to reach, it did not motivate them, possibly because science from their everyday lives was ignored in the learning material and obviously it did not interest or motivate students. Fensham (1988) described such 'desocializing' of the science curriculum as if it took place in a 'social and political vacuum'. Later on I felt an increasing urge to examine this phenomenon further, in a historical context.

Although I did not formally start considering or studying the 'new science' phenomenon in an Icelandic context until some decades later, I participated in various related developmental projects, services and assignments in science and mathematics education after this, where I had the opportunity to encounter and reflect upon such 'new science' churns in various contexts, although this experience of mine as a novice teacher in the Eastfjords school was without doubt the clincher. It provoked my concerns that things were not functioning as expected and thus needed further consideration or examining. The study proposed here reflects upon these experiences and interests, both personal and professional, and ultimately academic too.

Thereby my experience in educational research and practice is best explained in a historical context, comprising professional development and participation in policy making that goes back to the seventies, first as a student, later as a student teacher, then a novice teacher in lower-secondary schools for 16 years, a public official and adviser working for the state and municipalities, a school administrator, and finally as an academic in the Iceland University of Education and the University of Iceland. Actually I should consider myself as what Paul L Posner (2009) termed as 'pracademic' (practitioner + academic), someone who observes his subject as sustaining a tenacious connection between educational practice and educational research, and inevitably educational policymaking too.

When I reflect on my experience as a 'pracademic' in science education for four decades I cannot go beyond arguing that *historical consciousness*, as far as I am concerned, is a keystone for understanding the science curriculum. By historical consciousness I mean examining the relationship between curriculum levels, policy versus practice, intended curriculum versus the curriculum in action, as this relationship transforms over time. In this study I refer to this transformation as the *diachronic dimension*, while examining it as it appears at particular points of time is referred to as the *synchronic dimension*. I am arguing that this transformation needs to be analysed and interpreted as 'real duration' (Bergson, 1946), because it includes an amalgam of different views and ideas, featuring complex causalities and interactions, dynamic in nature. Furthermore I consider it unfortunate to isolate oneself outside or beyond the flow of events if one aims at understanding this transformation; I see my self as a partaker in all events addressed in this study.

Interpretations by the researcher of this study are considerable, because the study is to an extent what has been labeled 'a practitioner-researcher' work (Lodico, Spaulting & Voegtle, 2006), an insider investigation in the author's own area of practice; part of the data collection and analysis is built on sources from my own professional and educational settings. I consider my educational and professional experience delineated above as a valid rationale for applying such *practitioner researcher data*. And my intense participation in development programs by the end of the last century, for example as an organizer of the operation of model schools in Reykjavík 1999-2002, gave me an opportunity to gather valuable data about intriguing ways of implementing an intended national curriculum, in this case the 1999 science curriculum.

1.2.5 Reflections

Since the time I ended my lower-secondary education, through the period I attended grammar school, and through my time in teacher training (ITT), and until my first two years as a teacher in lower-secondary schools, the ‘new science’ and ‘new math’ waves from the 1960s affected my work to a great extent, first as a student and then as a teacher. I certainly did not realise then, that I was a partaker in the most surreal reform in the history of compulsory schooling. In science and mathematics education this was the era of abstract conceptions, theoretical sophistication and learning that was supposed to take place in a ‘social and political vacuum’. The makers of this policy apparently believed that the most effective science and math education would be abstract thinking, encouraging students to think and act like real scientists or sophisticated scholars.

For me as a student and later as a teacher in compulsory schools this experience almost felt analogous to what Alice in Wonderland experienced when she fell through the rabbit hole. Though the ‘new science’ and the ‘new math’ curricula were introduced as logically structured, it felt more like the authors and policy makers were playing with logic, as if they were deliberately turning things upside-down. In lower-secondary school I had felt confident with the science program offered in *Gagnfræðaskóli Vesturbæjar*, and the first year in grammar school had made sense. But after that the wonderland of abstraction and theoretical sophistication started to open, comprising subject matter like the SMP project in mathematics, and the CHEM study in chemistry.

After practicing teaching for a few years I participated in all kinds of innovation efforts where policy makers, practitioners and researchers tried to highlight the importance of educating young people by taking into account their intrinsic motivation and need to relate new knowledge to something meaningful from their prior experiences. But somehow I felt that all such efforts acted as weak ‘churns’ comprising no less confusion than the ‘new science’ and the ‘new math’ curricula. Consequently I wondered if there were other possible malfunctions at hand than deciding on contents and methods. Did those that participated in all these transient efforts realise and discuss the underlying philosophy that led the way? Did they debate on the significance of science education, why young people were supposed to study science? Or what was relevant to study in science? Did they debate on possible means and milieu for learning and assessing science and scientific literacy? Or how transient ideologies accounted for the transformation of the science curriculum?

1.3. Research Papers

The thesis rests on the idea that science curricula, like other school curricula, are social phenomena. The school science curriculum for compulsory education is such a phenomenon; *ad infinitum* it keeps transforming due to socio-cultural developments and political ideologies affecting its contents and structure. Therefore it should be studied as being of 'real duration' (Bergson, 1946), ongoing and indivisible, featuring an amalgam of transient ideologies (Kelly, 2009; Kliebard, 1986; Schiro, 2008).

1.3.1. The Conception of Transformation and its Meaning

Although the papers about transformation of the science curriculum (Articles I-III) were written in a different order, Article II first, then Article III and last Article I, they were envisioned in one discursive context. All of them presented the science curriculum as changing persistently like all other phenomena in our world, entailing that stagnation does not exist.

Articles II and III firstly made the point that although reform periods occur as cycles in education where the pendulum swings between antonymous philosophical views such as liberal-progressive and conservative-traditional, it should be noticed that every time a new period begins the stage will inevitably be different from ever before (Popkewitz, 1998). Thus the whole system transforms in a linear manner, although ideologies seem to wax and wane.

The second point made was that in spite of large-scale systemic reform efforts like the 'new science' curriculum reform in the 1960s and 1970s, changes seemed to become marginal when it came to the curriculum in action; the intended 'major' changes turned out to appear as miniscule in the actual process of teaching and learning. The third point made was that despite what Schiro described as perennial wars between educators over what the nature of the school curriculum should be, the actual transformation appeared more like what Darwin explained as evolution:

> Complex systems evolve from more simplistic predecessors and favorable mutations are preserved because they prove advantageous for survival and are consequently passed on to future generations. Eventually they accumulate and form completely new organisms … Dan Dennett (as cited in Papert 1997) called such an evolution in socio-cultural systems a 'Darwinian design', meaning that the most important tranformations in the education system come about by evolution rather than by deliberate design. (Article II, p. 709).

Transformation as constant evolvement is thus presumed to be an inevitable law of nature. Resistance to progress and the power of traditional practices in schools seem to be an inevitable law of nature too. The fourth and last point made is that schools and teachers have their own theories of an ideal curriculum and it is natural to resist ideas that conflict with them. According to the articles about transformation the routine instructional process in the classroom has a tendency of being conserved and retained while new ideas are met with scepticism. Technology, ICT as an example, is an important part of transformation that has typically evoked defense mechanisms in schools. But research affirms (John, 2005; Bennett, 2003) 'that transactions do occur where teachers gradually reconciliate with information and communication technology (ICT) and establish new meanings and accommodations. But the process is obviously a 'Darwinian design', i.e. slow and evolutionary, highlighting that favorable modifications (mutations) survive because they prove beneficial for the system and are consequently passed on to future generations (Article II).

Article III, titled *'Transformation' of the Intended Science Curriculum - A tension between instrumental and liberal purposes*, contains findings from analysing the intended science curriculum for Icelandic compulsory schools in force from 1960 to 1999. A classification of curriculum ideologies was used as a model for analysing the data and the results revieled a tension between what was identifyed as 'instrumental' and 'liberal' purposes of science learning. The 'instrumental purpose' was described as generating scientifically-educated individuals by transmitting objective content that they needed to pick up and be able to recite. The 'liberal purpose' was described as preparing individuals to become critical human beings and enhancing their informed autonomy.

1.3.2. Transformation: A Diachronic Perspective

Article I embodies findings from analysing the intended science curriculum for compulsory education in effect from 1960 to 2010. The official curriculum guides issued by Icelandic educational authorities in 1960 (in force 1960-1976), 1976 (in force 1976-1989), 1989 (in force 1989-1999) and 1999 (in force 1999-2010) were analysed with respect to rationale, aims, content, and role of teachers and pupils.

The transformation of the official curriculum was studied from a *diachronic perspective*. In Article II this transformation was conceived of as dualism between instrumental and liberal purposes, a struggle between opposing views like left and right politization, or progressive and traditional views on education. In Article I this idea was elaborated futher, where curriculum development was seen as holistic interpretation on the one hand, viewing the curriculum as process-development oriented, and on the other hand as mechanistic/reductionist interpretation, viewing the curriculum as content-product oriented.

As indicated above the contents of the curriculum guides were analysed with respect to six commonplace aspects of curriculum development, the position of teachers, the position of learners, the role of subject matter, the role of milieu, the extent to which the curriculum developers adhered to a content/product model, and the extent to which they adhered to a process/development model on the other hand. A content-product model was defined as focusing mainly on facts to know and skills to master and thus knowledge was conceived of as an end to proceed towards, a product to be manufactured. A process-development model was defined as placing the learner at the centre, viewing cognitive development and learning experiences as significant aspects of education rather than prescribed objectives and contents. Each of the six aspects was assessed by a five point rating scale (Article I), indicating its intensity (1 very weak; 2 weak; 3 moderate; 4 strong; 5 very strong). The analysis was conducted by defining the points of the scale, and discussing the contents of the four curriculum guides, their structure, context and meaning, where attention was directed at the position of learners, teachers, subject matter and milieu. The authors' prior experience and knowledge of the intended science curriculum and other curricula also helped when discussing and deciding on results. Summaries of findings were presented as radar graphs based on the above described rating scale (Article I).

1.3.3. Five Science Teachers Study

Articles IV and V are based on interviews and on-site observations with five science teachers conducted in 2005, illustrating their conceptions about science learning and teaching and use of ICT with respect to the 1999 curriculum and the educational policy reflected there. The policy of the 1999 curriculum comprised three main perspectives: First, much clearer and more precise objectives than ever before and the readoption of centralised national examinations; second, constructivist ideas on learning and teaching; and third the application of information and communication technology (ICT) in science education.

The two articles explain the results of interviewing the five science teachers and observing their on-site conditions and teaching styles. Two conceptions were employed in analysing the teachers' ideas about learning and teaching and their subject-specific pedagogy regarding school science (Article IV). Firstly a so-called seven-frame-model of teaching and learning was applied, in which commonplace curricular concepts like goals, contents, methods and assessment were taken into account. Secondly the analysis was based on a definition of three types of teacher professionalism, portrayed as dependent professionalism, independent professionalism and collaborative professionalism. Dependent professionals were seen as following the official curriculum guidelines and other regulations closely and building their work on experience rather than theory. Independent professionals were seen as conceiving themselves as professionals who evaluated and determined the needs of their pupils, preferred to work alone and make their own decisions about development. The third type, the collaborative professional, adhered to working together, accepted joint responsibility and was willing to undertake self-evaluation.

Article V reports on the five teachers' use of information and communication technology (ICT) and their ideas of teaching and learning science with ICT. To describe and analyse the use, the study drew on the *Computer Practice Framework* (CPF) developed by Twining (2002), on a model of the suitability of ICT for developing procedural knowledge in science (Baggott, LaVelle, McFarlane & Brawn, 2003), and on the different roles given to students when ICT is used in science (Newton & Rogers, 2003), such as receiver, explorer, creator or reviser.

1.4 Contribution of Practitioner Research

As explained above this study is partly an insider investigation of my own area of practice. My participation in surveying and developing the status of science education in Reykjavík compulsory schools for the Reykjavík Centre of Education (RCE) at the end of the last century and organising the establishment of model schools, was an opportunity to gather data about the implementation of new ideas emerging in the revised national curriculum that came into force in 1999. Some years after the 'new curriculum' came into force in 1999, in the beginning of the 2000s, I also had an opportunity to study its implementation by participating in the *Intentions and Reality Project* (IR). Likewise this was an opportunity to shed light on scenarios of the implementation of the new law brought into force 1995, the new national curriculum of 1999 and reintroduction of the centralised examination in 2001 that had remained inoperative since 1982.

As argued before a synchronic perspective is conceived to be complex and multi-planed. Taking a slice through the whole context, mainly focusing on 'the space' in which the curriculum actually takes place and is constructed, the space where policy making (intended curriculum) ends and the curriculum in action (implemented curriculum) takes over, we may expect to find flux instead of fixity. Presumedly, practitioners prove to view their profession differently, will use the official curriculum in different ways, and will have different communal uses for it (cf. Widdowson, 1996, p. 22– 23)

1.4.1 School Science at the Turn of a New Century

The landscape of science education in Iceland changed at the end of the last century with legal changes from 1995 and a new curriculum from 1999. In preparing the policy and work schedule for the school year of 1997-1998, the administrators of RCE, the Reykjavík Centre of Education (i. *Fræðslumiðstöð Reykjavíkur*), held brain-storming meetings with various groups and agencies to gather ideas about main goals and focus areas. Among other important results from these meetings were commitments to improve education in mathematics and science (termed i. *raungreinar* in RCE´s files). It should be noted that the Icelandic word *raungreinar* means 'real science' indicating a focus on the empirical view of science and a scientific method based on evidence of the senses, which is an important idea with respect to the main research problems this study focuses on.

In August 1997 I was employed as an educational advisor at the RCE (Appendix III). During the period from 1997 to 2003 I conducted several projects, large and small, such as meetings, CPD courses, studies and development projects. Among significant projects were a small-scale study on the status of physics and chemistry learning and teaching in Reykjavík's compulsory schools (Þórólfsson & Birgisdóttir, 1998; Appendix III, RCE-II), and a meeting with representatives from pivotal institutions (Appendix III, RCE-I), the Icelandic Teacher Union, The Iceland University of Education, The Faculty of Science of the University of Iceland, curriculum developers from The Ministry of Education, and The National Centre of Educational Materials. Finally, the establishment of four model schools in school science was probably the most significant project. In addition to that my work included an overall effort to promote the role of science, mathematics and technology in compulsory schools in general.

As argued in chapter 2.4.1 of this thesis, the miscellaneous understandings of the concept of *natural science* proved to be a problem through all developmental work in the area and the discourse accompanying it. Both specialists and laymen have expressed different ideas about the nature and contents of school science as a subject in the curriculum. Judging from the discourse and the discordant ideas featuring this discourse, school science should rather be conceived of as an area within education or even a 'wide and complex field of ideas' within public education. Some people seem to view this complex field of education as general science, an integration of life science and physical science, closely linked to daily life and natural milieu. Others look at it from an aesthetic, humanistic or even a value-laden viewpoint, promoting learning about the beauty of nature, conserving natural phenomena, and focusing on environmental issues. Finally the legacy from the 1960s also had strong advocates, where this field of education was considered as comprehending the academic disciplines, such as physics, chemistry and biology, i.e. the discipline-centred or subject-centred view as presented in curriculum theory.

Suggestions in the report on the results from the brain-storming meetings reflected a mixture of these different ideas as did the discourse and debate that followed about an effort to improve education in natural science, technology and mathematics (Fræðslumiðstöð Reykjavíkur, 1997; Fræðslumiðstöð Reykjavíkur, 1998; Þórólfsson, 1997) and the development of model schools. Among formal recommendations from the brain-storming meetings mentioned above there was the establishment of such 'core schools (i. *kjarnaskólar*) with ideal facilities for showing how to teach, offering CPD courses' (Fræðslumiðstöð Reykjavíkur, 1997).

Organising an effort to improve education in science and mathematics with respect to current ideas surfacing in national and international discourse at that time, was certainly not an easy job given the confusion about the nature of science as a school area. Current ideas were reflected in surveys that Icelandic schools had participated in, such as IEA's *Third International Mathematics and Science Study* (TIMSS) (Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly, 1996), trends appearing in Western science and mathematics curricula emphasising standards and objective learning outcomes on the one hand and constructivist ideas about learning and teaching on the other hand. Additionally the effort was to aim at trends in Icelandic curriculum development that were emerging in the draft of the new 1999 curriculum and recommendations from scholars and other specialists related to the revision of the science curriculum (MESC, 1997). Furthermore, considerable attention was still rendered to humanistic, value-oriented and environmental concerns, as had been emphasised in the 1989 curriculum.

Finally, the discussion about Iceland's participation in the international survey, OECD *Programme for International Student Assessment* (PISA), started in 1997 aiming at evaluating education systems worldwide by testing the skills and knowledge of 15-year-old students. Among other influential ideas of PISA were OECD's view on 'scientific literacy', i.e. to what extent young people at the end of compulsory education, were able to apply their knowledge to real-life situations and consequently be equipped for full participation in society (OECD, 2004). It should be kept in mind that PISA data were intended to provide governments with an effective tool to shape their policy making.

1.4.2 Model Schools

When I started my work at the RCE the 1989 national curriculum had been in effect for eight years, and criticism was felt from many directions that its aims and contents were considered too open-ended and inexplicit, and socially oriented at the price of subject oriented goals and academic contents (cf. Article I). Furthermore central control of science education had been weak for a long time and centralised testing had not been effective since 1983. The results from the 1997 meeting indicated that most of the representatives that attended the meeting agreed about commencing the following efforts:

- School science needs intensive attention and enhanced external and intrinsic control and support
- Systematic evaluation of science learning and teaching in schools is needed
- Centralised tests (i. *samræmd próf*) are likely to promote science learning, but special precaution is needed regarding the selection of contents for the tests, development and application.
- In-depth revision of pre-service and in-service education of teachers and their professional development
- Hands-on learning, field trips and out-door learning need more attention
- Integration of contents, learning tasks and organization of learning
- Teachers' efforts in organizing hands-on learning need more appreciation and understanding with respect to working hours and pay
- Natural science needs recognition as an important subject area throughout all compulsory education.
- Finally: What Icelandic students learn in science, how and when, must not be subject to discretion or coincidence.

(Appendix III, RCE-I, p. 1-2)

The above recommendations were more or less considered and responded to through various continuing professional development courses, meetings, lectures and debate

about science curricula and learning materials. Among developmental issues in RCE's work schedule for the year 1999 was a clause about an effort in natural science, where it was declared that four schools would start working as model schools in school science (i. *móðurskólar í náttúruvísindum*) in fall of 1999.
Originally the model schools were four, but as the project progressed one of them left the project and another changed its course and focused mainly on outdoor/environmental learning with equal emphasis on social studies as school science. The *Model School Project* in Science was funded by the Reykjavík municipal authorities to build learning programs according to aims in the 1999 curriculum. The aim was to promote mutual partnership among the model schools and share effective practices with other compulsory schools in Reykjavík.

Activities at three model schools were used as sources of data in this study. The schools were assigned pseudonyms in this thesis, the first as *West Elementary School* (WES) and the second as *East Comprehensive School* (ECS). The third model school, the one that deviated from the original plan is named *Suburban Elementary School* (SES) in the study. These schools differ with regard to structure, learners' social background, size and organisation. When the project took place WES and SES had grades 1 to 7 (ages 6 to 12) and ECS had grades 1 to 10 (ages 6 to 15). WES and ECS were comparatively large by Icelandic standards, each with approximately 650 students, but SES was smaller.

In addition to my experience as a central partaker in the project, supported by documents related to my approach to the development of the model schools, I also draw on taped and transcribed interviews I had with two teachers from WES, and one teacher from ECS, and a final report delivered to RCE from ECS. The project lasted for three school years, from autumn 1999 until spring 2002.

1.4.3 The IR Project

My participation in the *Intentions and Reality* (*IR*) project in 2006 and 2007 (i. *Vilji og veruleiki*) (Appendix IV) was an opportunity to focus further on the implementation of new law, new national curriculum and reintroduction of the centralised examination. The IR project comprised collecting data on education in science, technology and innovation from schools in five different areas of Iceland, the rural east, the coastal east, the rural/coastal west, the peri-urban southwest and the capital city.

I took part in the translation of a questionnaire, *Science Curriculum Implementation Questionnaire* (SCIQ), based on Dr. Brian Lewthwaite's doctoral research (Lewthwaite, 2003), which was developed to gather quantitative data about the teachers' views on five factors in school science: Time allocated to learning and teaching science, resources available, school ethos with regard to science, professional support for science teachers, and knowledge, skills and self-confidence of teachers. The Icelandic version of SCIQ is referred to as ISCIQ in this dissertation. School teachers answered the questionnaire before being visited by teams of researchers. With others I visted 10 schools and wrote seven reports on these visits. The visits included the collection of interview data from principals, teachers and pupils in lower-secondary grades, as well as on-site observations, classroom observations and assessments of teaching conditions.

The goal of the IR study was to examine the status of science education in the early 2000s following the above identified changes in law, national curriculum and testing, and additionally the participation of Iceland in international comparative studies. The study was a follow-up to one from the early 1990s (Macdonald, 1993). These changes occurred against a backdrop of:

> … developments in science and technology itself, the need for a scientifically and technologically literate workforce, the role of information technology in modern life and the massification of secondary and higher education … The value of the study lies in the contribution it can make to the development of science and technology education in Iceland in the 21st century and to discussions regarding proposed changes in lower and secondary education. (Appendix IV, IR-I, p. 4)

The main research question of IR (below) focused first and foremost on the space in which the science curriculum was constructed (Macdonald et al., 2008), i.e. the space into which policy-makers brought forward the national policy as a curriculum text and teachers brought forward their skills and knowledge. The main research question reflected this space as the *gap between the intended curriculum and the enacted curriculum*:

> *What is the nature of the gap between the intended curriculum and the actual curriculum in school science and technology – the intentions and the reality?*

As explained in the IR final report (IR-I), not only policy makers and teachers are able to interpret and affect what happens in this construction space of the curriculum; principals and local authorities can also play a central role in supporting school science or neglecting it, and furthermore books and digital resources can play a part too. So ‘the space is a heavily contested area, and each and every stakeholder is affected by the views on science held by the economy and by society’ (IR-I, p. 9). The IR project resulted in 27 reports, over 40 conference presentations and proposals, 11 published journal articles, and 2 seminars/workshops. The data comprise information about school science in over 20 schools.

To conclude this description of my part as a practitioner-researcher working for the RCE by the end of the last century, I want to highlight that I conceive the above data from my own professional settings, whether they were addressed in articles or not, as part of the evidence I build upon in this doctoral study, keeping in mind the importance of ‘historical consciousness’. This is explained in more detail in section 3.2.

1.5 The Structure of the Thesis

The purpose of my research was to explore the transformation of the school science curriculum in Icelandic public schools, i.e. what has characterized its evolvement since the publication of the first formal national curriculum in 1960 and how curriculum ideologies may account for this transformation. Concepts borrowed from linguistic research, diachrony and synchrony, reflect the purpose and nature of study, i.e. examining the evolvement of the curriculum over time requires taking into account the diachronic dimension, and examining how it operates simultaniously in various contexts requires accounting for the synchronic dimension. The contents of the thesis are divided into four main chapters, followed by a list of references and appendices.

Chapter 1, *The Thesis and its Context*, comprises five main sections. The first one, *The Thesis and its Sources*, explains its main focus and nature, theoretical perspectives, and articles it is based upon. My personal context is presented and accounted for in the second section, *Personal Perspectives*, explaining my participation in 'policy churns' and my situation as a learner and 'pracademic' in the Icelandic educational system, where the conception of 'historical consciousness' is highlighted. The third section, *Research Papers*, portrays the fundamental ideas and findings of the five research articles based upon. The fourth section, *Contribution of Practitioner Research*, illustrates how I use my experience as a researcher and practitioner in various contexts as sources of data, both as a partaker in managing projects and educational research at the University of Iceland and as an organiser and advisor in projects aimed at promoting and developing school science in compulsory schools. Finally there is this section about the *Structure of the Thesis*.

Chapter 2, titled *Review of Literature*, is divided into three main sections. First, there is a section titled *Curriculum,* comprising an intensive coverage about the conception of curriculum and curriculum theory, its multiple definitions, manifestations, nature, and ideologies. The second section, *Curriculum Transformation*, addresses the idea reflected in the title of this study and discusses major concepts related to curriculum changes and reform. The third section titled *Natural Science as a School Subject*, gives a historical overview of trends and issues related to the evolvement of science as a curriculum field in public education. The fourth and last chapter of this section, *School Science in Icelandic Compulsory Education*, explains some main trends and issues regarding transformation of the school science curriculum in Icelandic compulsory education.

Chapter 3, titled *Main findings*, presents central themes in the findings with respect to the two main perspectives of the thesis, the diachronic dimension focusing on the transformation of the official science curriculum 1960 to 2010, and the synchronic dimension focusing on the transformation of the intended and the implemented curriculum 1995 to 2007.

Chapter 4, titled *Discussion and Implications* discusses some vital issues found in the data, such as an interplay between curriculum designs and ideologies, the myriad of ideas found in school science practices, nature and history of science, constraints and external interventions, teachers' part in delivering school science, the space between intentions and reality, and finally some fundamental implications that have emerged from the findings.

Appendix I, *Transformation of the Science Curriculum*, explains and contains papers I – III:

- *A perspective on the intended science curriculum in Iceland and its 'transformation' over a period of 50 years*
- *'Transformation' of the science curriculum*
- *'Transformation' of the intended science curriculum. A tension between instrumental and liberal purposes*

Appendix II, *Five Teachers Study*, explains and contains papers IV – V:

- *Views of five teachers in compulsory schools on the learning and teaching in science*
- *Learning science with ICT*

Appendix III, *RCE*, contains files and information about the science effort that I took part in at the turn of the last century for *Reykjavik Centre of Education*.

Appendix IV, *IR,* contains files and information about the *Intentions and Reality* project.

CHAPTER 2

REVIEW OF LITERATURE

School science:

... the most revised of established curricular areas, at least in respect of proposals for reform (Donnelly, 2006)

... The view that the science curriculum must change has become so common as to be an orthodoxy (Donnelly & Jenkins, 2001)

... subjects [such as science] are not monolithic entities but shifting amalgamations of sub-groups and traditions (Goodson, 1994)

2.1 Curriculum

An Icelandic curriculum theorist, Andri Ísaksson (1983), defined ‘curriculum’ as a ‘plan or guide about what should occur (be learnt and taught) in schools’, which is similar to Hilda Taba’s simple definition, a ‘plan for learning’ (1962). What such definitions have in common is that they imply that the curriculum is a written document, an instrument for managing the process of education on a national level, school level or classroom level.

Despite their simplicity the above definitions may have sufficed most part of the twentieth century. But, according to scholars in the field, they are in effect too superficial to apply to the actual complexity of an ‘educational curriculum’, which is a societal undertaking, interpreted, understood and used in multiple ways and contexts, and consequently comprises many meanings and definitions (Grundy, 1987; Kelly, 2009; Marsh & Willis, 2003; van den Akker, 2010).

2.1.1 Multiple Definitions

Traditionally, perspectives on the curriculum and its nature have been reflected by the etymology of words that we use, the term ‘curriculum’ referring to a racecourse, and ‘syllabus’ meaning a list of topics to be covered. By such reasons these words reflect the idea of a ‘plan for learning’, a learning programme to be ‘raced through’ in schools before examinations: ‘... for many students, the school curriculum is a race to be run, a series of obstacles or hurdles (subjects) to be passed’ (Marsh & Willis, 2003, p. 7).

But despite the conception of the curriculum being a prescriptive tool for managing this race that we call education, many influential scholars have identified it as a socio-cultural construction (Apple, 1979; Giroux, 1982, 1990; Pinar, 2004), a ‘social artifact’ (Goodson, 1994), that we ought to be watchful about treating as ‘given’. This means that we need to examine ‘the relationship between school curriculum content and form, and issues of school practice, process and discourse’ (Goodson, 1994, p. 114). It connotes the idea of providing a clear connection between an individual’s understanding and the social contexts which that individual belongs to.

Therefore curriculum theorists maintain that multiple types of curricula are functioning in schools. Three of these are most prominent and relevant for science education as discussed in this study. First, there is the virtual written, overt or explicit curriculum (Eisner, 1985; Cuban, 1995; Wilson, 2005). This is the formal part of learning and instruction, the official curriculum presented as written material, curriculum guides, curricular frameworks and courses of study. The four curriculum guides analysed in this study, the 1960, 1976, 1989 and 1999 curricula, apply to such definitions.

Second, there is the hidden, implicit or covert curriculum (Eisner, 1985; Longstreet & Shane, 1993; Wilson, 2005), the unwritten messages, positive or negative, that students receive from their school environment, informal codes of conduct, behaviors and attitudes that are learnt through interactions with teachers, administrators and others in schools.

Third, there is the null curriculum (Eisner, 1985), i.e. the elements or content that we decide not to teach and thereby give students the notion that these elements are not important:

> … if we are concerned with the consequences of school programs and the role of curriculum in shaping those consequences, then it seems to me that we are well advised to consider not only the explicit and implicit curricula of schools but also what schools do not teach. It is my thesis that what schools do not teach may be as important as what they do teach. I argue this position because ignorance is not simply a neutral void; it has important effects on the kinds of options one is able to consider, the alternatives that one can examine, and the perspectives from which one can view a situation or problems. ... (Eisner, 1985, p. 97)

Eisner's point was that school personnel have the power to make conscious decisions as to what is to be included and what is to be excluded from the intended curriculum. As for the 'overcrowded' science curriculum it is in fact impossible to cover everything that people want to include in it, so there are topics and subject areas, possibly subjects *per se*, that are bound to be excluded from the written curriculum, and thus students get the message that the content or processes involved are not significant enough to be included.

Many other definitions have been suggested and used for school curricula; for example Harold R. W. Benjamin's idea of the the saber- tooth curriculum (Benjamin, 1939), written under the pseudoname of J. Abner Peddiwell. The *Saber Tooth Curriculum* was a satirical narration of how traditions of schooling resulted in resisting well-founded reform incentives. Benjamin's narration can easily be transformed to the situation of science curricula today, since scientific and technological knowledge provided in many curricula and science textbooks may have become outdated soon after the text was printed and equipment used for hands-on learning, for example measuring instruments like scales, tend to be far from following the methods and technology of everyday life.

Finally curricula can be defined according to their functionality on different levels. Thus Cuban (1995) suggested that there are at least four different curricula in use. First, the official curriculum which education authorities expect teachers to teach and assume learners will embrace. Second, the taught curriculum, that is what teachers actually choose to teach. Third, the learned curriculum, i.e. all knowledge, performances, values and attitudes that learners really learn in school. Finally, Cuban identified the tested curriculum, i.e. the limited parts of the other three curricula that find way into examinations and standardized tests. Cuban (1995) considered it a problem of great concern that the taught and learned curricula were largely ignored when effectiveness of schools were under discussion.

2.1.2 Curriculum: Content-Product or Process-Development

There is an obvious contrast between ideas of a *content-product oriented curriculum*, that focuses typically on prescribed facts to know and skills to master, and a *process-development oriented curriculum* which is perceived as dynamic in nature, 'an attempt to communicate the essential principles and features of an educational proposal in such a form that it is open to critical scrutiny and capable of effective translation into practice' (Stenhouse, 1975). Content-product orientation entails knowledge as an end to proceed towards, a product to be manufactured, while process-development orientation reflects what actually happens when learners interact with their social, cultural and physical milieu. Kelly (2009) portrays the process-development view as a:

> ... concern with the nature of the child and with his or her development as a human being. Its purposes are plain, although it has often been accused of lacking clear aims. It sees education as the process by which human animals are assisted to become human beings. (Kelly, 2009, p. 91)

However it should be noted that emphasising the development of human beings, and seeing education as a 'process by which human animals are assisted to become human beings' might entail the transmission of essential knowledge and values embedded in academic subjects such as physics and mathematics, as well as promoting morally good attitudes and visions of a humane society. This suggests that theorising about curriculum and its development presumably involves inextricable questions concerning the nature and content of a curriculum, and the principles it is based on. Such questions are inextricable because answers will always give rise to further questions and problems; whatever view one takes about education or curriculum development, 'that view will be predicated on certain assumptions about the nature of knowledge and a particular set of values.' (Kelly, 2009).

If we placed the curriculum on a continuum with the *content-product view* at one end conceiving learning and teaching as fixed and preplanned, and the *process-development view* at the other end conceiving learning and teaching in a state of flux, open-ended, we would easily find justifications for either of these views with well-grounded logic. To understand distinct visions of such kind, we need to consider them in the historical context in which they have developed (Schiro, 2008). Studying *the transformation of the science curriculum* is such an endeavour.

2.1.3 Curriculum Theory – Curriculum Ideologies

The stage for curriculum and its tranformation that was set in American education in the beginning of the twentieth century was undoubtedly representative for the development in Western education as a whole, though of course most of the ideas were transplanted from Europe's 18th and 19th century educational rhetoric and even further back in history.

On the one hand, there was the notion of organising curriculum through what was labelled as 'scientific management', seeing education as a technical exercise, setting goals, objectives and plans, implementing them and measuring the outcomes (Bobbitt 1918/1928 as cited in Flinders & Thornton, 2009). For the past 60 years Ralph Tyler (1949) has been the major ideological source for such curriculum work supported by systems and taxonomies of various of learning objectives (Bloom, 1956; Krathwohl, Bloom & Masia, 1964; Marzano, 2001), typically aligned with psychometrics, i.e. quantitative methods aimed at measuring developments of human abilities.

On the other hand, there was a focus on learning experiences and cognitive development as significant points of orientation, seeing education as a learner-centered exercise, where schooling ought to be adapted to the child and that the child's authentic activity was seen as a requisition for education. John Dewey was without doubt the major advocate for this ideology along with many others, such as the Italian physician Maria Montessori. Although such theories about curriculum may have sounded revolutionary at that time and received labels like 'the new method' and 'the new education', they were indeed not new. They had long roots with complex origins and emergence: 'They were not the work of one isolated worker or of some pedagogue who succeeded by pure deduction in deriving a whole psychopedagogic theory of child development from some particular piece of research. They became inevitable on many fronts simultaneously' (Piaget, 1969, p. 146). Here Jean Piaget was referring to workers like Maria Montessori in Italy, David Decroly in Brussels, Francis W. Parker and John Dewey in America and the 'active school' (g. *Arbeitschule*) that took root in vocational training institutions in Germany (Piaget, 1969).

As many scholars have argued (Kliebard 1986; Ornstein & Behar-Horenstein 1999; Ellis 2004; Schiro 2008) there are various ways of theorising about curriculum and developing it. Here it will be addressed philosophically and historically. And furthermore as means of contemplating current curriculum practice and policy making, that deal with questions about goals and content of the science curriculum, what knowledge, values and skills have been considered of most worth and other related issues. Four major models (Schiro 2008; Kliebard 1986) are applied for explaining and illustrating how such ideologies appear in the science curriculum and related documents and discourse. Kliebard called them humanist (or mental disciplinarians), social efficiency, developmentalist (or child study), and social meliorists. Schiro labelled them scholar academic ideology, social efficiency ideology, learner-centered ideology, and social reconstruction ideology.

As indicated above curriculum theory deals with the nature and content of the curriculum, why we approach it the way we do and what we hope to achieve through it. It connotes seeking answers to fundamental questions like what should be the purpose of the school, what should be taught and learned, how and why, what counts as legitimate knowledge, and how to administer and organize the school environment and its context. 'Educational experience' is a key concept in this perspective. One of four key questions in Tyler's rationale (Tyler, 1949) was: 'What educational experiences are related to those purposes [of the school]?', i.e. what subject matter, learning problems, educational challenges, ideas, values, learning environments and learning conditions are of most relevance? According to curriculum specialists the quest for answers to such questions is best described as warfare (Kliebard, 1986; Schiro, 2008).

Schiro (2008) describes this search as ‘a perennial war’ between educators over what the nature of the school curriculum should be. He prefers to use the word ‘ideology’ instead of the more common term philosophy for ‘curriculum visions, philosophies, doctrines, opinions, conceptual frameworks, and belief systems’ that control education policies. He also points out that all curriculum ideologies represent ideals ‘abstracted from reality, and not reality itself’ (2008, p. 11) resulting in various positions and a combination of different views among educators and others involved. Consequently ideologies or philosophies related to curriculum are bound to amalgamate in obscure and unpredictable ways when it comes to implementation.

But inevitably there are extreme ideologies that conflict, at least when it comes to policy talk. James Donnelly (2006) assigned ‘liberal’ and ‘instrumental’ purposes of science education as two controversial motives for tension, but according to Donnelly the two kinds of purpose are not distinguishable, i.e. ‘curricula can serve both purposes’ (2006, p. 635) which is bound to be an important issue with respect to decisions on what to include in the curriculum and what is to be ignored as less worth topics and ideas. Donnelly’s idea of a liberal purpose of science education refers to what has been explained as child-centered or student-centered ideas of educational philosophy (Schiro, 2008), but an instrumental purpose is what has been explained as subject-centered, curriculum-centered or teacher-centered. If curriculum is placed on a continuum, then student-centered curriculum endorsed by liberal politics would fit well on one end and a subject-centered curriculum (teacher-centered, curriculum centered) endorsed by conservative politics on the other. Visions of educational experience on the liberal pole would certainly be in contradiction to the conservative ones on the other pole. As a matter of fact, educational experience would be of central concern among liberals while extremists on the other end, focusing on test scores, ‘the bottom line’, would typically want to ignore educational experience as an argument, or as plain-spoken by William Pinar:

> By linking the curriculum to student performance on standardized examinations, politicians have, in effect, taken control of what is to be taught: the curriculum. Examination-driven curricula demote teachers from scholars and intellectuals to technicians in service to the state. The cultivation of self-reflexive, interdisciplinary erudition and intellectuality disappears. Rationalized as ”accountability,“ political socialization replaces education.
>
> (Pinar 2004)

Like Kliebard (1986) in his historical overview of the forces that shaped the curriculum in America between 1893 and 1958, Schiro (2008) depicts four major curriculum ideologies, each of which embodies distinct opinions on the purpose of schools, what should be taught, what learning consists of, under what conditions, how teachers should instruct, and how to assess learning and teaching. The four ideologies Schiro envisions are the *scholar academic ideology*, *the social efficiency ideology*, *the learner centered ideology*, and *the social reconstruction ideology*. Schiro delineates the conceptual framework for each of the ideologies. In a comparative overview he brings out conceptions of aims, knowledge, learning and teaching, the learner (the child) and evaluation (2008).

According to Schiro the scholar academic ideology aims at transmitting the essence of the disciplines, knowledge is envisioned as didactic statements, learning and teaching as transmission of knowledge, the learner (the child) as a neophyte in a hierarchical community of the academic disciplines, and evaluation as gathering objective data on student learning achievement.

The social efficiency ideology educator aims at carrying out a task for society efficiently, providing knowledge that gives learners the ability to function in society, viewing learning and teaching as a process by which learners' behaviour are shaped by agents outside themselves, learners (children) as raw materials to be shaped, and evaluation as means to determine acceptance or rejection (pass or fail).

The aim of the learner centered ideology is to pursue learners' needs and interests and help them make meaning with respect to their prior conditions and knowledge, knowledge is considered personal, a derivative of each individual's learning and growth, learning and teaching as an interactive exercise where everyone is learning and growing at his or her own pace, the learner (the child) is unique and viewed as a whole person and a self-propelled agent of his or her own growth and as a self-activated maker of meaning, and evaluation as means to promote learning and teaching for the benefit of the learner and the curriculum.

Social reconstructionists aim to reconstruct their culture and thus facilitate the best conditions with respect to the needs of all subjects of society, knowledge is supposed to give children the ability to interpret and reconstruct their society, learning and teaching should stress acculturation into an alleged good society, the learner (the child) is seen as a social being whose nature is defined by the society in which he or she lives, and evaluation should be subjective and take on a holistic approach assessing curricula and students with respect to the social situations in which they live.

2.1.4 Curriculum Levels and Components

Curriculum ideologies surface variously in different levels of the school system. As argued before, we need therefore to distinguish between ideologies and rhetoric that shape policy, prescribed curricula and syllabi on the one hand and actual practice in real-life classrooms on the other hand. Otherwise stated: We need to consider which level of the system is at issue and what type of curriculum we are referring to in each case. Tangible change applies more likely to the ideal curriculum, its rationale and rhetoric, than the 'curriculum-in-action' (Fullan, 2001; Tyack & Cuban, 1995), though it should be kept in mind that reform is a 'steady work' in all corners of the school system (Elmore & McLaughlin, 1988). Van den Akker (2010) outlines some basic conceptions that are valuable when analysing curriculum and curriculum development in this respect. First there is a differentiation between at least four levels of the education system, the system level (*macro*), the school level (*meso*) and the classroom level (*micr*o) and the individual level (*nano*). Secondly van den Akker empasises a common destinction between the intended, implemented and attained curriculum:

> Intended:
> - the *ideal* curriculum: the original vision underlying a curriculum (basic philosophy, rationale or mission);
> - the *formal* curriculum: the vision elaborated in a curriculum document (with either a prescribed/obligatory or exemplary/voluntary status);
>
> Implemented:
> - the *perceived* curriculum: the curriculum as interpreted by its users (especially teachers);
> - the *operational* curriculum: the actual instructional process in the classroom, as guided by previous representations (also often referred to as the curriculum-in-action or the enacted curriculum);
>
> Attained:
> - the *experiential* curriculum: the actual learning experiences of the students;
> - the *attained* curriculum: the resulting learning outcomes of the students.
>
> (van den Akker, 2010, p. 3)

Thirdly van den Akker identifies the various components of the curriculum that need attention and balancing, the first and most important one being *the rationale*, 'which serves as major orientation point, and the nine other components are ideally linked to that rationale and preferably also consistent with each other' (p. 4). The other nine are *aims and objectives*, *content*, *learning activities*, *teacher role*, *materials and resources*, *grouping*, *location*, *time* and *assessment*. When considered in light of the four ideologies Schiro envisioned (2008), all these components are worthy of critical inspection. To underline the inter-consistency of the components and their vulnerability, van den Akker visualised them and explained their nature as a spider web. But as a matter of course their relevance varies across the curriculum levels (macro, meso, micro, nano) and representations. Curriculum documents at the macro-level would normally focus on the rationale, aims and content while all ten components are relevant for the next two (meso and micro). The component of assessment is relevant for all levels and 'careful alignment between assessment and the rest of the curriculum appears to be critical for successful curriculum change' (p. 5).

Educational experience is of central concern when theorising about the curriculum, and we certainly find conflicting visions when it comes to curriculum development with respect to learning contexts and experiences:

> From a socio-political stance, it seems often more appropriate to describe it as a war zone, full of conflicts and battlefields between stakeholders with different values and interests. Problems manifest themselves in the (sometimes spectacular and persistent) gaps between the intended curriculum (as expressed in policy rhetoric), the implemented curriculum (real life in school and classroom practices), and the attained curriculum (as manifested in learner experiences and outcomes). ... It is noteworthy that we are beginning to see more blended approaches that integrate various trends and characteristics of recent design and development approaches in the field of education and training…
>
> (van den Akker, 2010, p. 7)

According to Marsh and Willis (2003) there are three different approaches considered most notable to curriculum development. First there is *Tyler's rational-linear approach*, that broke new ground for curriculum workers when it was published in 1949. This approach has also been labelled a procedural and technical approach, because it focuses on objective steps to be followed in educational decisions. According to Tyler's approach the behaviours of students were of high significance in devising objectives for appropriate learning experiences instead of simply identifying content to be covered, which has been considered the traditional way of approaching curriculum. Secondly there was *Walker's deliberative approach*, also named Walker's naturalistic model. It was called descriptive (described what curriculum developers actually did) and normative (described what curriculum developers ought to do), because it was empirically based; it built on studies of planning that had occured during real curriculum projects, where deliberation was needed in identifying problematic situations and reaching consensus on solutions and decisions. Thirdly there was *Eisner's artistic approach*, that identified curriculum development as an ongoing process of making personal meaning and conveying meaning, where the curriculum was considered a medium through which individuals learned 'how to deepen' (Marsh, 2006, p. 210). Thus this approach differs from the others on account of its emphasis on personal perception and experiences. Both Tyler's and Eisner's approaches placed emphasis on learning experiences and how the curriculum would be 'lived' by its users, but Walker's approach was criticised on the other hand for having been directed almost exclusively to the designing of a curriculum, but not pertaining to its users after the curriculum is designed and being concerned about how it is actually experienced by its students (Marsh & Willis, p. 81).

Assessment is an interesting indicator for such blends of approaches and ideologies, and does indeed reveal what sorts of learning experiences curriculum developers preeminently embrace. And assessment is a powerful instrument because of its washback effect; control and potential changes of assessment inevitably control and change student learning and teachers instruction, either in a positive or negative sense (Cheng, Watanabe, & Curtis, 2004). This has led educators and researchers to focus on the consequences of uses of assessment and its results, or what Samuel Messick (1994) labelled consequencial validity. He argued that particular uses and interpretations of assessment results required evaluation of its intended and unintended consequences. Thus, in evaluating the validity of assessment, there will always be questions that need answers with respect to consequences of assessment (Gronlund & Waugh, 2009), e.g.: Did it improve motivation? Did it improve learning? Did it improve self-assessment skills? Dit it encourage good study habits? Or did it have unfavourable effects in some important areas? Did it for example discourage independent learning?

Assessment is a powerful instrument because of its distinct purposes and how they are reached. First, assessment is the instrument that politicians use when they seek to control education (Black, 2000; Pinar 2004), and as such comports strongly with the scholar academic and the social efficiency ideologies according to Schiro's classification (2008), i.e. 'assessment of learning' for the purpose of certifying mastery of intended learning outcomes and assigning grades. Second, assessment is the optimal means that educators have to support and motivate learning and teaching, referring to 'activities undertaken by teachers, and/or by their students in assessing themselves, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged' (Black & Wiliam, 1998). This mode of assessment, referred to as 'assessment for learning' (Black & Wiliam, 1998), comports with the learner centered ideology (Schiro, 2008). Third, assessment, at its best, is an important part of education *per se*, interwoven with learning, teaching and curriculum development at all levels (Harlen, 2000). Referred to as 'assessment as learning', this mode of assessment provides learners (actually both students and teachers) with opportunities to continuously reflect on their work, on what they learn, how they learn it and what directs their learning processes, thus promoting metacognitive awareness. Consequently assessment as learning assumes that students have an important role in assessing and organising their own learning, and in fact also the learning of their peers to a certain extent. Assessment as an ongoing undertaking in the learning process comports with all four of the curriculum ideologies Schiro identified (2008); at best it is interwoven with the whole process of education or enculturation (Hodson & Hodson, 1998), whether it is subject-centered, student-centered or society-centered.

More than four decades ago David Ausubel (1968) called for an increased reliance on childrens'prior cognitive structure as 'the most significant independent variable influencing the learner's capacity for acquiring more new knowledge in the same field' (Ausubel, 1968, p. 130). This trend, which is a major characteristic of constructivist theory of learning, has led to the requisition that assessment recognises pupils' prior knowledge about scientific phenomena in addition to the various sorts of learning and performance outcomes that make up the curriculum (Fensham 1985, p. 425). Accordingly the science curriculum for compulsory education does indeed feature various sorts of criteria for learning, comprising complex activities, interpretive in nature with respect to assessment, where learning and learning outcomes depend not simply upon objective measures of knowledge and skills, but rather upon a comprehensive *partneship* between teachers and students (Bell, 2000) where formative and summative assessment amalgamate. To demonstrate this complexity Enger and Yager (2001) identified six important domains aligned with the American National Science Education Standards (National Research Counsil, 1996) for developing and assessing science learning. They contended that assessment approaches 'should include multiple measures of what students know and can do as a result of their learning experiences. The use of multifaceted assessment approach has the potential to provide a better profile of student understanding in the six domains, and a more holistic assessment approach deals with the "whole student" ' (Raizen & Kaser, 1989, as cited in Enger & Yager, 2001). The six domains Enger and Yager argued for were:

1. *Concept domain*. Knowing and understanding concepts are considered central to science learning and instruction. This domain comprises facts, laws, principles, theories, and 'the internalized knowledge held by students', but at its best it promotes linkages instead of a concept-in-isolation approach, where students have concrete experiences with concepts before moving to abstractations.
2. *Process domain*. Exploring and investigating natural phenomena require hands-on and minds-on activities and inquiries. Students observe, use space and time relationships, classify, measure, infere, communicate, predict etc.
3. *Application domain*. Students demonstrate that they not only grasp the meaning of information and processes, but that they are also able to apply them in new situations, e.g. solve problems that occur in daily life or other contexts where the application of science concepts and skills comes in use.
4. *Attitude domain*. This domain refers to attitude toward science, interest in science, attitude toward scientists and their work and a scientific attitude (open-mindedness, honesty, scepticism etc.). Examples related to learning and assessment are developing positive student attitudes toward science in general and decision making about social and environmental issues.
5. *Creativity domain*. This domain calls for an openness in the classroom, an acceptance of ideas, a try-new-things approach, and a so called go-with-the-flow approach. Its essence is the generation of new ideas, unusual ideas, metaphors and combining objects and ideas in new ways.
6. *Nature of science domain*. It is considered important that students learn how science has developed through history, how it has affected social and economic factors of human society and what roles scientists have played in this process.

(Enger & Yager, 2001, p. 2–11)

Consequently assessment needs to be multi-planed and wide ranging if it is to be considered valid and relevant, but at the same time focused both on student's prior ideas and achievement of learning, and thus reflecting blends of curriculum approaches and ideologies.

2.1.5 Reflections

Portraying the development and use of the curriculum as a technical exercise, setting goals, objectives and plans, implementing them and measuring the outcomes has influenced science education for over a century under the rubrics of 'scientific management'. Although the opposite of this scientific-technical view, the view that Jean Piaget called a 'whole psychopedagogic theory of child development' (1969), has been described as new (‘the new method’ and ‘the new education’) and revolutionary, its roots are in fact older and deeper than the roots of the scientific management ideology. These two views on curriculum development are like two juxtaposed currents that have flowed through the history of education, sometimes conflicting with each other, at other times not. Advocates for both have argued that the two currents should not be understood as completely antonymous: Instead the fundamental issue was to conceive them as ‘not of new versus old education nor of progressive against traditional education but a question of what anything whatever must be to be worthy of the name education’ (Dewey 1938, p. 90).

Whatever is worthy of the name education, or enculturation as envisioned by some current learning theories in science education, in particular social constructivist theory (Hodson & Hodson, 1998), it involves basic questions about goals and content of the science curriculum, and what knowledge, values and skills are considered of most worth. Schiro identified four different ideologies in this respect: the scholar academic ideology, social efficiency ideology, learner-centered ideology, and social reconstruction ideology. All these ideologies have affected trends and issues in science education. A key conception in that respect is learning experience, that is what kind of subject matter is appropriate, what learning problems, educational challenges, ideas, values, learning environments, milieu and learning conditions are of most relevance. Consequently the conceptions of hidden curriculum and null curriculum, in addition to the official written curriculum, are of high importance with respect to science education.

When theorising about curriculum we need to consider all levels related to the organisation of the school: the system level, where the basic philosophy and rationale of the curriculum are formed and elaborated in official documents; the school level, where the curriculum is interpreted and locally formalised; the classroom level, where the curriculum is enacted, i.e. the actual instructional process; and the individual level, where the curriculum is experienced by students and results appear as learning outcomes. Van den Akker (2003) identified ten important components of the curriculum, the rationale being the most important and serving as an orientation point for them all. When the curriculum is analysed, all these components are relevant and affect each other.

Approaches to curriculum development vary. Marsh and Willis (2003) considered three such approaches as most notable: Tyler’s rational-linear approach, Walker's deliberative approach, and Eisner's artistic approach. Learning experiences received considerable attention with respect to Tyler’s approach and Eisners’s approach but Walker’s deliberative approach was criticised for not considering how the curriculum would be experienced by its students. Bearing in mind the alignment of the curriculum through all levels of the system and with respect to the hidden curriculum and the null curriculum in addition to the written curriculum, learning experiences are a central component. Assessment is an important aspect of curriculum development because of its washback effect and consequential validy and its relevance at all levels. Assessing students’ ideas, knowledge, skills and attitudes in science is of great concern in that sense, because of its complexity and various domains that comprise learning and assessment in science.

As Schiro (2008) remarked all curriculum ideologies represent ideals ‘abstracted from reality, and not reality itself’. This seems certainly to be the case for the development of the science curriculum in Iceland. It appears as comprehending different views and philosophies that amalgamate uniquely as they have appeared in explicit (written, overt) and implicit (hidden, null) curricula.

2.2 CURRICULUM TRANSFORMATION

Transformation of the curriculum refers to the assumption that the science curriculum is a dynamic phenomenon not a static one, presuming that whether it is conceived of as intended, implemented or experienced, it steadily passes through complex processes to accommodate diverse ideas and needs of parties with a vested interest. Thus the school system as a whole transforms steadily reflecting incremental changes on the one hand, progressively going on at all times, everywhere. On the other hand it reflects what has been portrayed as reform movements or 'educational changes'. According to Walker and Soltis (2009, p. 80) this means that 'ideas are not only generated from knowledge-centered, student-centered, and society-centered perspectives, but also from a persception that the educational system isn't working properly at a particular time' and reform is needed to improve the system. Schiro (2008) explains this enduring process as a consequence of conflicting values or ideologies concerning the purpose and organisation of the school, nature of learning, role of the learner, role of the teacher and the purpose and implementation of evaluation and assessment.

Thus educational changes constantly occur. Reform is probably the most frequently used term regarding such changes. Its meaning suggests that parties involved continuously want to reshape and rectify the system striving to bring solutions to problems, help follow societal developments or offer new and presumedly more fortunate opportunities and resources than were offered before. Reforms vary in scale and origin (Walker & Soltis, 2009). They can focus on curriculum, content and the organisation of learning, or they can be more comprehensive dealing with the structure of the whole system, for example a systemic change from central governance to de-centralisation. Reforms are typically considered as top-down processes from system level policy formation to implementation in the classroom level. But some reforms are 'particularistic' or contextual involving specific cases, schools or school districts but not affecting whole communities or a nation as a whole (Fullan, 2001; Elmore & McLaughlin, 1988). Reforms can originate from groups of any kind, politicians, scholars, unions or businesses (Walker & Soltis, 2009). Whether they are large-scale or small-scale we assume that they usually affect everyone associated with education – students, teachers, parents, school officials, government agencies, textbook publishers, and more. For the past decades the national curriculum in Iceland has undergone similar reforms or transformations as other Western school curricula (Macdonald 1993; 2000) affected by similar philosophical or socio-cultural ideologies and belief systems.

2.2.1 Reform: A 'Steady Work'

Although 'educational reform' is the most commonly used term in the literature in this respect terms such as 'educational change' and 'educational progress' are also found. Their meanings are conditional as applies to the basic concept for this study, *transformation*, and it is important to iterate that these terms are often used interchangeably (Horn, 2002); but the rationale of this study actually demands that their different meanings and implications are highlighted when they appear. As discussed above the term ‘reform’ usually denotes that a system supposedly needs improvement and new solutions are offered, while ‘change’ implies that it will be altered. Assuming that the term ‘progress’ means growth and improvement it is important to emphasise that neither reform nor change guarantee progress of that kind. But when progress is conceived as a more relative term, i.e. a constant evolvement or advancement without preconditions, it can be applied to curriculum and theorising about its essence, since curriculum is evidently a dynamic phenomenon and its development is ‘steady work’ (Elmore and McLaughlin, 1988).

Walker and Soltis (2009) use the phrase ‘problem-centered approach to curriculum’ in a similar sense as Schiro (2008) when describing a ‘social reconstructionist curriculum’, where reformers generally assume that our society faces problems or unfortunate developments that need to be corrected; the school is considered the ideal place to change such situations and the curriculum is obviously the ideal instrument to implement them. Such developments may include multiple kinds of problems, such as pollution, global warming, energy shortage, illiteracy, limited societal relevance, or a shortage of technically and scientifically educatated citizens. At all times there have been problems in need to be corrected or situations to be reconstructed. Examples of such reform endeavours have affected science education ever since it became a part of school curriculum, for example pedagogical progressivism and life adjustment education during the first half of the twentieth century aiming at promoting the social relevance of education. During the 1950s a different orthodoxy began to emerge and finally got the upper hand as a new reform movement, contrasting the progressive reform movement. This was the ‘new science’ curriculum reform of the 1960s and 1970s advocating academically sophisticated subject matter featuring strong criticism against social relevance and life adjustment science. By the end of the 1970s ideas of scientific literacy and science for all changed the landscape again, resurrecting ideas of social relevance and understanding of the nature and role of technology and science in society. By the end of the century still new reform ideas emerged reflecting an amalgam of a back-to-basics trend, detailed aims and objectives according to social efficiency ideology and constructivist ideas in science education. All the above reforms seem to have left lasting traces in the existing science curriculum (Elmore & McLaughlin, 1988; Fullan, 2001; Tyack & Cuban, 1995; Walker & Soltis, 2009), confirming that it seems harder to remove things out of the curriculum than adding new ones (Stinner & Williams, 2003).

2.2.2 Instrumental and Liberal Purposes

Michael Fullan (2001) described the essential cause for educational change with the metaphor of a battle between two ships, one named *Accountability*, the other *Professional Learning Community*. They are ‘passing in the night, stopping occasionally to do battle, in the dark‘ (p. 267). Fullan’s main argument was that we face persistent transformations driven by different philosophical perspectives that constantly move us from one stage to another, but *nota bene* we never experience the same scenario as before, the battle never occurs under the same conditions twice. Fullan‘s argument is worth noting that doing battle ‘in the dark‘ is obviously ill-advised. Instead it might be wise to cultivate empathy towards the ideas of others, get a sense of ‘the big picture’ and place one’s own ideas and work in that wider perspective. Most educators would undoubtedly agree on this point. But the argument is strong that perennial controversies over what is to be taught and learned and how it might best be undertaken and certified are important preconditions for the system to evolve normally. This has certainly been the case for the science curriculum, where teachers face consistent tension between content coverage and accountability through standards, testing and international studies on the one hand and on the other hand student-centered, personalised and context-based approaches to teaching and learning science (DeBoer, 2002).

A major purpose of this study is to examine the nature and progress of such drivers for curricular changes as they have appeared in Icelandic science education, and how the alleged battle has evolved, referring to Fullan’s metaphor (cf. Fullan, 2001), how, why and by what powers the science curriculum keeps transforming over time and presumedly appears as ‘not fixed, but flux’ at any one time. It should be highlighted that such dualism, ‘thinking in either-ors’ (cf. Dewey, 1938), is well known in educational literature. James Donnelly (2006) named those two ships ‘instrumental’ and ‘liberal’ and thus referred to different ideas about the purpose of science education. He described science curriculum reforms as involving tensions between the ‘instrumental’ purpose and the ‘liberal’ purpose. According to Donnelly the former focused on the provision of a scientifically-educated workforce for society through the control of the curriculum by politicians or ‘science educators’, the accountability ship in Fullan’s metaphor, and the latter focused on students as growing human beings and the promotion of their informed autonomy, the community-of-learners ship in Fullan’s metaphor.

As affirmed by Black and Atkin (1996) in their monograph about case-studies in science, mathematics and technology education for the Organization for Economic Cooperation and Development (OECD), a myriad of national reports, papers and books proposing educational reform in science alone have been issued in developed countries in recent decades, implying that science is indeed one of ‘the most revised of established curricular areas, at least in respect of proposals for reform’ as Donnelly argued (2006, p. 623). Donnelly and Jenkins (2001) portrayed the perpetual impulses for curricular changes in science education as a sort of religious correctness: ‘The view that the science curriculum must change has become so common as to be an orthodoxy’ (p. 2) . Furthermore Black and Atkin‘s report (1996) suggests that science curricula transform in complex and multiple ways; if they were studied synchronously, as was done in the case studies for OECD, you would find that no system was in phase with any other, a situation that Widdowson called ‘flux, not fixity‘.

Ever since natural science became part of mainstream education in the nineteenth century the science curriculum has in fact undergone constant transformations with respect to content, structure, conceptual framework and underlying philosophies (Atkin & Black, 2003; DeBoer, 1991). This gives the impression that teaching and learning in science supposedly change distinctly in a similar fashion as transformation happens in the natural world, for example when a butterfly emerges from a chrysalis; it transforms its nature and how it functions in real life settings by passing through recurring cycles. Does the science curriculum undergo similar transformations?

2.2.3 Transformation of Discourse or Transformation of Real Practice?

The literature (Fullan, 2001; Elmore & McLaughlin, 1988; Tyack & Cuban, 1995; Sigurgeirsson, 1992; Sigþórsson, 2008; Millar, Leach, Osborne & Ratcliffe 2006; Labaree, 2005) indicates that despite that educational rhetoric does seem to pass through recurring cycles, actural educational practice does not seem to go through oscillations to the same extent due to the an elemental conservatism of schooling (Walker & Soltis, 2009; Tyack and Cuban, 1995). An American historian, Ruth M. Elson (cited in Walker & Soltis, 2009, p. 96), concluded from her research that schools appeared to be 'guardians of tradition' preventing discourse and innovative ideas from affecting 'real practice'. Consequently there appears to be a gap between predominant ideologies and rhetoric on the one hand and real practice on the other. When we claim that the science curriculum undergoes constant changes, with ideas appearing as recurring cycles, it probably applies more to discourse and ideas than to real practice. Consequently we need to consider which level of the system is at issue because real change applies more likely to the ideal curriculum or rationale than the implemented curriculum. The prescribed curriculum may change regularly, but marginal changes are more probable in real-life classrooms (Elmore & McLaughlin, 1988). Furthermore the metaphor of the cycle is not valid for real-life settings in education because it means returning to the same place and situation again and again, 'seemingly denying the possibility of progress' (Tyack & Cuban, 1995), which is *ipso facto* inconceivable.

Tyack and Cuban's metaphor of 'tinkering toward Utopia' (1995) might therefore be more proper to describe science education reform at the school level than actual transformation as happens for example in the natural world. The word tinkering has a derogative meaning, giving the impression that reformers fiddle with the complex system we call school without realising how it functions and therefore not anticipating the consequences of their tinkering. 'Utopia' as Thomas More presented it in his novel five centuries ago was as an ideal system, actually an unrealistic ideal, impossible to achieve. In an educational context, tinkering towards such an ideal may therefore seem like pursuing unattainable ends, goals not capable of being accomplished.

Real-life interaction in classrooms does not comprehend the same pattern as discourse about ideal teaching and learning. Real school practice embodies complex settings that are typically 'particularistic' (Elmore & McLaughlin, 1988) and unique with respect to culture, context, space and time, incurring that each school, learner and teacher functions in an unpredictable manner and their interactions vary significantly (Fullan, 2001; Elmore & McLaughlin, 1988). Due to the complexity of school structures and diverse practices at the classroom level an external pressure for change may imply a positive experience for a given situation while it may bring a negative experience for another (Walker & Soltis, 2009; Elmore & McLaughlin, 1988). Ultimately, outside interventions are doomed to fail in bringing solutions that work for every setting. Each school and classroom must learn and develop in context because of the uniqueness of their situation (Fullan, 2001) and the effects on schools, learners and teachers will therefore vary significantly.

Even major waves of large-scale curricular reforms seem to have been tinkering and thus led to marginal changes in schools due to intrinsic flaws, resistance to changes and the power of traditional practices in school. The period from the mid-1950s to the mid 1970s was a period of flux and change in Western education or as Ivor Goodson put it (2010, p. 194), a time when influencial scholars assumed that schooling and curricula should be 'revolutionized', 'the maps of learning redrawn'. Goodson characterised the multinational curriculum reform in the 1960s as a sort of 'tidal wave': 'Everywhere the waves created turbulence and activity but actually they only engulfed a few small islands; more substantial land massess were hardly affected at all, and on dry land the mountains, the high ground, remained completely untouched' (p. 194). The research literature indicates (Hurd, 1970 as cited in DeBoer, 1991; Bourdieu & Passeron, 1977; Apple, 1979; DeBoer 1991; Fensham, 1988; Jóhannesson, 1991; Macdonald, 1993; Finnbogason, 1995; Keeves & Aikenhead, 1995; Fullan, 2001) that the reformers of education in the 1960s, in Iceland as in other countries, may have overlooked some important features of successful transformations of science education.

Despite a number of strengths and advantages of the 'new science' wave for public education, such as promoting primary school science and inquiry learning, modernising the contents of physics and chemistry, establishing biology as a coherent field and stressing concepts in depth and in context instead of school book coverage, the science curriculum reform in the 1960s embodied weaknesses, such as ignorance of societal relevance and not considering everyday life experiences of students as means of developing their interest in studying science. The commonplace error of not taking into account students' pedagogical needs and preconditions, i.e. habits, attitudes, motivation and prior knowledge was an intriguing example of such failures (Hurd, 1970 as cited in DeBoer, 1991; Fullan, 2001).

Furthermore, reform never was and never will be completely under the control of the reformers themselves. External factors affect curriculum transformation, i.e. changes in economic and social structures. Due to societal developments, conflicting political ideals, economic and technological advances and other complex factors the science curriculum evolves just as any other phenomena. Such external factors 'set parameters and possibilities for internal change' (Goodson, 2005, p. 107). . Consequently, it may be more accurate to talk about an unforeseen progress or evolvement of the curriculum than talking about a deliberate reform; it reflects a 'Darwinian design' where favorable mutations are preserved, rather than a deliberate design.

2.2.4 'We can not Step into the Same River Twice'

Nevertheless, progress is a physical fact, 'we can not step into the same river twice' and the arrows of time move only in one direction. The definite direction of time enables us to remember the past and never experience it exactly the same way over again. Although the past is unattainable we are able to study it and diagnose previously experienced problems and learn from them, which tells us that using the cycle metaphor is in fact irrational (Tyack & Cuban, 1995). Another important issue of concern is the fact that we live in an increasingly disordered and chaotic world; or as Stephen Hawking has attested (1998) with his conception of the thermodynamic arrow of time, a measure of an increasing disorder of the world, along with the psychological and the cosmological arrows: The essence of our existence precludes history from repeating itself.

Education and consequently the science curriculum change persistently like all other phenomena in our world, stagnation does not exist. Reform periods have occured as cycles in education where the pendulum swings from liberal-progressive to conservative-traditional and back again. Ideologies have their heydays, they wax and then they wane but they always leave enduring traces. Furthermore, every time a new period begins, the stage will inevitably be different from before. Constructivist pedagogy is for example certainly not a new conception in education. Although constructivist pedagogies concerned with science learning in the beginning of the 21st century draw on the writings and work of Lev Vygotsky, John Dewey, and many other thinkers of the early 20th century progressive era, it is apparent that the context is different today from what it was before. 'While the names of the authors are the same in both periods, contemporary school reforms exist within an amalgamation of institutions, ideas, and technologies that are significantly different from those of the turn of the [20th] century' (Popkewitz, 1998).

By the end of the 'new science' wave that had symptomised the science curriculum in the 1960s a new theme emerged, the 'new new wave' or 'new progressivism'. It surfaced in Western education in the 1970s and was characterized by the need for an enlightened citizenry, instead of educational elite emphasising the structure of academic disciplines. It brought out the relationship between science, society and technology (STS), and the integration of science with other human interests under the rubrics of *Scientific literacy, science for all* and *science for citizenchip*. This new theme, referred to as the 'new progressivism' by Ravitch (1983), had 'hardly reached the shores of Iceland' by the end of the 1980s:

> Rebuilding school science will require us to recognise that in a citizen's science, knowledge should be considered functionally, in terms of its social purposes...Constructing a science curriculum for the citizen demands a new understanding of scientific capability and new view of the nature of science and values in science. These are issues which have hardly reached the shores of Iceland... (Macdonald 1993)

Although the ‘new new wave‘ embodied a different rationale from the one that dominated in the 1960s, ‘the idea that the public should have some knowledge of science’ goes back at least to the beginning of the twentieth century (Laugksch, 2000; Shamos, 1995; Harlen, 2000, 2006; Fensham & Harlen, 1999) and the term ‘scientific literacy’ has functioned in science education rhetoric for decades, probably appearing in print for the first time in an article by Paul DeHart Hurd (1958) more than half a century ago, where he wrote about the importance of ‘closing the gap between the wealth of scientific achievement and the poverty of scientific literacy ...’ (p. 14) and stressed the relevance of science for all in the modern curriculum:

> Science can no longer be regarded as an intellectual luxury for the select few. If education is regarded as a sharing of the experiences of the culture, then science must have a significant place in the modern curriculum from the first through the twelfth grade. (Hurd 1958, p. 13)

2.2.5 Real Duration - ‘Not Fixity, but Flux’

As explained before in this text the ideas of *diachrony* and *synchrony* are used as a framework for explaining the transformation of the science curriculum. This denotes that the curriculum evolves constantly (*the diachronic dimension*) and wherever we ‘take a slice through it’ (the *synchronic dimension*) we find ‘not fixity, but flux’ (Widdowson, 1996). It also entails that albeit reform periods seem to occur as more or less regular cycles theoretically, we will never experience the same scenario twice in real practice, ‘we can not step into the same river twice’, and simultaneous scenarios may differ enormously from one context to another; the enacted science curriculum in one school may differ immensely from science curricula in other schools.

Despite the notion that trends and issues in the history of science curriculum reform can be studied as isolated scenarios and courses of events, featuring self-contained observations within determinate time limits, this study rests rather on the idea of time and history as real duration, ongoing and indivisible. It is grounded in what Goodson (2005, p. 106) described as ‘trajectories of influence and causation which are linked to the past, or indeed pursued longitudinally from the past into the present and from there into the future’. The progressive era in the first half of the last century, the reform wave in 1960s, the new progressive era, and back-to-basics trends somewhere in between, are considered as superficial lables of this ongoing duration. Although enquiry and discovery learning are considered as originally presented in the reform period during the 1960s, the fact is that such ideas have been known since the end of the 19th century as the heuristic method (Harlen, 1996) and they are still held in high esteem in science education, and though scientific literacy and science for all are considered as belonging to the new progressive era, they are certainly not new ideas, known through most part of the twentieth century (Harlen, 2006; Fensham & Harlen, 1999)

2.2.6 Reflections

The history of the science curriculum features an interesting transformation involving a tension between two main forces. On one hand there is an ideology embracing accountability and 'instrumental' purposes focusing on the provision of a scientifically-educated workforce for society. On the other hand there is an ideology embracing 'liberal' purposes stressing a student-centred science curriculum and focused on students as growing human beings and the promotion of their informed autonomy in a socio-cultural context. Michael Schiro (2008) developed a typlology of four different ideologies reflecting these forces variously. Reports from meetings and case-studies conducted by Black and Atkin (1996) for the OECD affirm a myriad of accounts of educational reform in science attributed to such ideologies. They indicated that curricula transform in complex and multiple ways, both in general and also particularistically. Most important tranformations seem to come about by evolution rather than by deliberate design (Articles II & III).

This complexity of the transformation of the curriculum is a firm rationale for studying it as real duration, ongoing and indivisible. The curriculum evolves constantly, the same scenario will never be experienced twice and simultaneous scenarios differ from one context to another. The arrows of time move only in one direction, and despite the fact that the past is unreachable, we are able to study it by exploring and diagnosing a variety of historical data and thereby clarify previously experienced problems and learn from them.

Real school practice proves to be 'particularistic' with respect to culture, context, space and time. Hence, outside interventions hardly bring solutions that work for all settings. Policy formation and changes of the intended curriculum do not necessarily purport changes of the implemented curriculum. We need to distinguish between predominant ideologies and rhetoric on the one hand and real practice on the other. When we claim that the science curriculum undergoes constant changes, with ideas appearing as recurring cycles, it may apply mostly to discourse and ideas and less to real practice. Furthermore the metaphor of the cycle is not valid for real-life settings in education. It would mean returning to the same place and situation again and again, which would contradict the fact that the curriculum progresses, 'we can not step into the same river twice' and the arrows of time move only one way; every time a new period begins, the stage will inevitably be different from before.

The Icelandic science curriculum for compulsory education appears to have evolved in similar ways as in other neighbouring countries, constantly being revised. It was strongly influenced for example by the reform wave in the 1960s and 1970s. The Icelandic school system has had its share of the bureaucratic, standardisation trend pertaining to international comparative studies like TIMSS and PISA and their homogenising influences and furthermore constructivist and liberal ideologies have affected educational rhetoric with respect to science curriculum transformation. But there have been some indications of specificity. They concern policy and decision-making, teacher education and educators' (lack of) awareness about issues related to science education, and the position of science in the official curriculum.

2.3. Natural Science as a School Subject

Everyone agrees that education in science *per se* is important for all students at all stages of the school system and '[the science curriculum] has grown and developed ramarkably during a period of only 150 years' (Keeves, 2003, p. 1135). Despite that the history of science curricula is short compared to the curricular history of other academic subjects it has, since its genesis, been recognised by distinguished educators as an important preparation for all aspects of human activity. Herbert Spencer (1820–1903) was convinced that science should form a major part of the school curriculum. In an essay written in 1859, *What knowledge is of most worth?* he responded without deliberation that the answer to this question was *scientific knowledge*, because we needed such knowledge to pursue the leading kinds of activities which constitute human life:

> … –the uniform reply is–Science. This is the verdict on all the counts. For direct self–preservation, or the maintenance of life and health, the all–important knowledge is–Science. For that indirect self–preservation which we call gaining a livelihood, the knowledge of greatest value is–Science. For the due discharge of parental functions, the proper guidance is to be found only in–Science. For that interpretation of national life, past and present, without which the citizen cannot rightly regulate his conduct, the indispensible key is–Science. Alike for the most perfect production and highest enjoyment of art in all its forms, the needful preparation is still–Science. And for purposes of discipline–intellectual, moral, religious–the most efficient study is, once more–Science. (Spencer, 1969/1859, p. 93–94).

Spencer's arguments are indeed interesting with respect to the purpose and contents of science as a school subject. Since then there has been a determinate agreement about the importance of natural science. But there has not been as determinate agreement on the contents, structure and methods of science education. There is even less agreement on visions underlying the science curriculum, i.e. the basic philosophy or rationale it should build on.

2.3.1 School Science: An 'Overcrowded' Curriculum Field

Nevertheless science forms the basis of education in current school systems along with other so-called liberal arts in modern universities, i.e. literature, languages, philosophy, history, and mathematics, a legacy from the seven liberal arts of medieval European universities: grammar, rhetoric, and logic (the trivium) and geometry, arithmetic, music, and astronomy (the quadrivium). The traditional image of the science curriculum is sharing scientific content and processes with students in schools, normally including physical science (physics and chemistry) and life science (biology) as core content, and at times earth and space sciences in addition or alternatively.

Ever since science became a curricular area in public education about a 150 years ago it has undergone constant transformations (Donnelly, 2006; Atkin & Black, 2003; DeBoer, 1991). Ivor Goodson (1994) described its development as evolving from a low-status position within the curriculum, first promoting utilitarian and pedagogic purposes, which were the essence of the progressive movement, and later being defined as academic ‘disciplines’, with a rigorous body of knowledge and ties to university. George E. DeBoer (1991, p. 17) claimed that due to a great effort of scientists and some educators during the late 1800s the way was opened to the inclusion of science in the school curriculum. Since then its dimensions, contents and structure have constantly been reorganised and transformed, and there are persistent controversies about its purpose, nature and structure (Atkin & Black, 2003; DeBoer, 1991).). It has been influenced by different ideologies and learning theories that certainly do not share common philosophies, from behaviourism on the one hand setting clear learning goals linked to content of the academic disciplines and objectively assessing knowledge, to constructivism on the other hand requiring active participation of the learner and assessing subjectively for the benefit of learning and *partnership* (Bell, 2000) of all participants in the learning process.

However, there has been an agreement on a traditional image of the science curriculum as portrayed above, with physics, biology and chemistry as core elements. But despite that this image may sound incontestable and well defined, debates are steadily in progress over its aims and content; unity on what to teach, how, when and to whom does not seem visible at any time. Consequently the school science curriculum has become a ‘crowded place’, appearing alternately as ‘a carefully-tended garden’ to some people, and ‘a weed patch of trivia’ to others:

> ...someone was always coming up with some new scientific information that everyone should know, and few people ever suggested removing anything. The result is a science curriculum that has come to resemble a weed patch of trivia and esoterica rather than a carefully-tended garden of worthwhile knowledge. While science educators agree that the science curriculum needs to be less crowded, one science educator’s weed is another science educator’s flower, and so nothing ever seems to get removed. In other words, there is an agreement on the general principle but, as the old saying goes, the devil is in the details. (Stinner & Williams, 2003, p. 1027)

According to the curricular history of science it might thus be justified as a broad field in the school curriculum rather than a rigidly defined school subject, actually an overcrowded curriculum field that builds on continually expanding and hard-to-manage ‘academic’ disciplines compounded with other areas of learning. The academic disciplines compete for space in the curriculum, where historically biology, physics and chemistry have required and received most space in the curriculum. But through the history of public education other subjects have also strived for space in the science curriculum, such as zoology, botany, physiology, geology, geography, astronomy and cosmology. In addition to the so-called academic disciplines there has been a strong rationale for other areas and views in science education, i.e. a general science for all, scientific literacy, STS (science, technology and society), STSE (science, technology, society and environment), education for sustainable development (ESD), and in recent years STEM (science, technology, engineering, and mathematics). Thus the role of science as a curricular area has in a certain sense become ‘polymorphic’ meant to be learnt and taught with respect to multiple needs and purposes, in cultural, economic, social and political contexts. Deng (2007) contends that this purports different kinds of curricular insights and knowledge among primary and secondary teachers in addition to mere knowledge of scientific content originated in the old ‘parent disciplines’. Teachers need knowledge related to pedagogy, epistomology, psychology, technology and sociocultural issues, and additionally insight into related subjects such as mathematics, social studies and engineering.

Consequently it has been affirmed (Deng, 2007; Shulman, 1986) that being an educator or a curriculum developer in compulsory school science purports knowing or at least having insight into the contents of a number ‘academic’ disciplines and subjects, and furthermore you need to know how to promote scientific literacy, interest and critical thinking about the role and nature of science in our society. Shulman and his associates confirmed such ideas through their research project *Knowledge growth in teaching* (Shulman 1986; 1987), where they focused on how novice teachers transformed their previously learned content knowledge of academic disciplines into forms suitable for learning and teaching in classrooms, leading to their terms of *content knowledge*, *pedagogical content knowledge* (PCK), and *curricular knowledge*.

Most citizens in contemporary society presumably perceive public schools as agents that reflect and transmit knowledge, values, views, skills and wisdom that have prevailed in our culture. In science, as well as in other disciplines, an enormous body of knowledge and skills have accumulated that we do not want to be lost for future generations. But, as discussed earlier, history has taught us that science as a school subject is dynamic in the sense that its definition and role have chronically kept changing from one time to another which inevitably has raised controversies.

As indicated above, there have been strong arguments for including science as a core subject in the curriculum for over a century, but these arguments are intrinsically disparate. They imply different demands resulting in a tension between ideologies, and also two other conceptions or views related to differing ideoligies, on the one hand teaching science to all citizens for understanding and functioning in everyday life and on the other the needs of teaching science for future specialist jobs (Millar & Osborne, 2006). The Twenty First Century project, a pilot study commissioned by the English Qualifications and Curriculum Authority (QCA), is an eminent endeavor for resolving this tension between scientific literacy and science as preparation for advanced scientific studies (Millar & Osborne, 2006).

Science education for future specialist jobs calls for a discipline-based curriculum focusing on concepts and principles, while scientific literacy suggests a more general education emphasising personal development and citizenship. With an increasing focus on science education for all citizens scientific literacy has become a major theme within the science curriculum (DeBoer, 2000; Bybee & Ben-Zvi, 2003). Although it is not a clearly defined term among science educators there is an agreement that scientific literacy implies an understanding of science for general education purposes as opposed to education for careers in science. A simple conceptualisation of scientific literacy might be what the public needs to know about science, its nature, aims and ideas to be able to identify questions and problems of scientific nature confronting our society (DeBoer, 2000; Laugksch, 2000; OECD PISA, n.d., Bybee & Ben-Zvi, 2003).

Thus an intense introspection has constantly characterised the community of science educators and others involved in science education (Bennett, 2003, p. 15). Although good and less good answers are bound to be found for every context and at any time, a 'key to arriving at good, rather than less good, answers is informed decision-making, and it is here that research in science education has a contribution to make' (Bennett, 2003, p. 15). Icelandic science educators have gone through similar propositions and questions like educators in other western school systems. Problems like the following are frequently discussed: What sort of science content should be offered and to whom? What should be included and what should be excluded in the compulsory curriculum? Should there be one science course for all students whether or not they plan on further education in science? To what extend should the science curriculum be academic? To what extend should it be practical? To what extend socially oriented? To what extend vocational? And certainly 'one science educator's weed is another science educator's flower' when trying to arrive at good answers to such questions.

2.3.2 Trends and Issues – Deliberative Approaches

Since the wave of curriculum reform took place in the 1960s, school science has been perceived to a considerable extent as a basic preparation for further science education featuring foundational knowledge of academic disciplines like biology, physics and chemistry. In most countries there is still a general agreement on such emphases, either as an option at the adolescent stage in compulsory education (Atkin & Black, 2007) or as core component in the curriculum. But synchronously there is an agreement on the need for emphasising a public understanding of science and its role in society (Millar & Osborne, 1998; AAAS, 1993; De Vos & Reiding, 1999), i.e. introducing all students to major conceptions (big ideas) related to science and technology, such as the biosphere, the solar system, genetics, waves, viruses, bacteria and energy provision. Furthermore the need to address the complex interactions between science, technology, and society, and promote understanding of the nature of science has been accepted internationally as a major element in compulsory education (Fensham, 2004; Millar & Osborne, 1998; AAAS, 1993; Macdonald, 2000). Allyson Macdonald (2000) portrayed this synchrony of converse objectives and content at the dawn of the new century, together with emphases on constructivism and international comparison (TIMSS and PISA), as 'the three C's – *curriculum*, *constructivism* and *comparison*' (Macdonald, 2000, p. 63), a combination of different demands that inevitably embody contradictions in terms of learning and teaching, confirming what Stinner and William (2003) portrayed as a weed patch of trivia and esoterica rather than a carefully-tended garden of worthwhile knowledge.

Some researchers (Osborne & Dillon, 2008; DeBoer, 1991) have argued that content and pedagogy associated with the traditional science curriculum embracing the academic disciplines 'are increasingly failing to engage young people with the further study of science.' (Osborne & Dillon, 2008, p. 7), leaving haunting questions about what should be taught, why, when and how? And there is certainly no consensus as to how these vital questions should be answered. But there are trends and promising trials that might be called deliberative approaches. Two examples of such approaches are the *Algemene Natuurwetenschappen* in the Netherlands (De Vos & Reiding, 1999), a general science course that is compulsory for all students in grade 10 taught alongside the traditional science subjects that are optional in Grade 10, and *The Twenty First Century Science* curriculum in England (Nuffield Curriculum Centre, 2010). Both of them offer science for all students ensuring science education of universal value for all, meeting the needs of all students. But according to De Vos and Reiding's research (1999) the experience in The Netherlands shows that 'once a science-oriented approach is adopted, it becomes extremely difficult to escape from the shadows of the science teaching tradition.' (p. 718).

Views concerning how we learn, what we should learn, and under what conditions also control trends and issues in science education. Behaviourist theories promoting a *transmission-of-knowledge* view of teaching and learning fit well with the idea of science as a study of facts, theories, and rules to be memorized and practiced, where the teacher is conceived as a sage on a stage passing his wisdom down to students. The *transmission-of-knowledge* model has its uses in that respect indeed, and most of us have known teachers who accomplished such teaching methods with good results. This model has been predominant for at least one century, and other models, no matter what era they belong to, have proved difficult to comprehend and implement. In their coverage about the noted Eight-year study, conducted by the end of the progressive era in the United States, Marsh and Willis depicted this problem as an attitude, familiar to all educators, towards the subject–centered curriculum on the one hand, considered viable and workable and on the other hand the child–centered curriculum, considered attractive but unconvincing with respect to workability: '…the new ideas themselves-especially those about individual-centered curricula were difficult to understand, and the examples of individual-centered curricula that captured public attention (such as some extreme forms of child-centered pedagogy) seemed well outside the mainstream of American education.' (Marsh & Willis, 2003, p. 48). But it has its weaknesses and limitations and the Eight-year study, as have other studies since (Duit & Treagust, 2003), served to undermine some of the assumptions about the traditional subject-centered curriculum model (Marsh & Willis, 2003) where the teacher's central role is transmitting knowledge with the textbook as a basic medium.

2.3.3 The Student as a Scientist – Discovery Learning

Science curriculum projects carried out in the 1960s and 1970s under the rubrics of *enquiry learning* and *discovery learning* 'were developed to challenge the traditional "teacher-as-transmitter- of-knowledge" model of teaching and to present science to pupils as a way in which they could conduct their own inquiries into the nature of things' (Bennett, 2003). It was part of the multinational wave of curriculum reform that started in North America in the mid-1950s and lasted for more than two decades internationally. Van den Akker (2003) describes this reform wave as the origin of modern development for school science (p. 424). With federal involvement in allocating teaching and learning of science to the logical structure of the academic disciplines and the process of science, this 'new science' curriculum expected teachers and prominently students to think and act like scientists (DeBoer, 1991). The argument was that:

> …intellectual activity anywhere is the same, whether at the frontier of knowledge or in a third-grade classroom. What a scientist does at his desk or in his laboratory … are of the same order as what anybody else does when he is engaged in like activities–if he is to achieve understanding. The difference is in degree, not in kind. The schoolboy learning physics is a physicist, and it is easier for him to learn physics behaving like a physicist than doing something else. (Bruner, 1966, p. 14).

Behaving like scientists meant that the pupils were supposed to work with learning materials and equipment that required them to experiment and discover relationships, and to structure and make sense of these relationships. Students' practical work was at the center of science learning and teaching, or as Bennett (2003, p. 76) remarked, curriculum projects at that time were encapsulated by the much quoted expression, 'I hear and I forget, I see and I remember, I do and I understand'.

Ideas of discovery learning were supported by theories of cognitive development, most prominently under the influence of Jean Piaget's work that shaped beliefs about how students obtain, process and use knowledge (DeBoer, 1991; Bennett, 2003). Accordingly learners would not understand (learn, assimilate or accommodate) the meanings of fundamental concepts, for example time, space, chemical, force or energy, unless they were active themselves in dealing with problems and discovering structures. Such conditions were considered optimal for cognitive development since human beings attempt to make things viable as means to adjust to their environment and comprehend it. Learning the structure of physics as an example, meant learning physics the same way scientists did by trial and discovery, not the traditional way where the teacher transmitted bits and pieces of knowledge to students.

In his monograph, *The Process of Education,* about the Woods Hole conference held in 1959 Jerome Bruner organised the ideas about teaching and learning science and mathematics into four key themes: The role of structure in learning and how it may be made central in teaching, readiness for learning, intuitive and analytical thinking, and motives for learning (Bruner, 1966). The teacher-as-transmitter-of-knowledge model was considered unfavourable, because it meant producing knowledge unrelated to the essence of the subject itself and consequently not giving learners the opportunity to realise its structure and meaningful relations to other things: 'Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structured pattern, it is rapidly forgotten' (Bruner, 1966, p. 2).

Just as Bruner was concerned with the content and how it was presented, Joseph Schwab focused on the process by which scientific knowledge was generated (DeBoer, 1991), i.e. science as *enquiry*. To him it was important that both teachers and students understood that science knowledge embodied conceptual structures that constantly needed to be revised as the result of new evidence. Consequently the most effective way to learn science was through active engagement in the process of enquiry. According to Ronald D. Anderson (2007) enquiry (spelled *inquiry* in Anderson's writing) has persisted as a major theme in science education for about 50 years and still does, currently related to constructivist theories of learning in particular. But according to Anderson research confirms that its meaning has become ambiguous and many questions are being raised, such as: 'When someone talks about science as inquiry, learning through inquiry, or teaching by inquiry, are they talking about the same inquiry?' (Anderson, 2007, p. 807).

The 'new science' curriculum was an enormous enterprise. All over the world large amounts of money, time and expertise were spent in developing science education projects, but not nearly as much in other subjects (van den Akker, 2003). Iceland was part of that development. Through two officially appointed committees on science education in Iceland (ME, 1968; ME, 1969) this new wave had an immense impact on Icelandic science education in the late 1960s and 1970s (Macdonald, 1993; Jóhannesson, 1991), especially the national curriculum and the edition of learning materials based on the PSSC, BSCS and CHEM projects from America and the Nuffield project from England.

According to Paul DeHart Hurd (as cited in DeBoer, 1991) the 'new science' reform wave embodied a number of strengths and advantages for public education, such as promoting inquiry learning, focusing on significant concepts in depth and in context and being less concerned with coverage. But according to Hurd there were intensive weaknesses and disadvantages, such as the abstract nature and theoretical sophistication of the curriculum, ignorance of science in the social world and everyday life of students and little effort in developing students' interest in studying science. The idea of encouraging pupils to be scientists and the conceptual demands of the discovery science courses proved to be well beyond the ability of average students (Bennett, 2003).

Furthermore, despite the focus on pupils as scientists being active in their enquiry, an old ghost, the 'teacher-as-transmitter-of-knowledge model', was never far off. To learn physics behaving like physicists did not prove as easy for the pupils as expected, because science education was still operated under the rubrics of transmission pedagogy, meaning that all educational incidents and outcomes were pre-planned by the teacher and the curriculum. Whether the teaching style was defined as 'chalk and talk', 'question and answer', 'discovery projects' or 'individualized worksheets' (Goodson, 2005, p. 31), the same pre-active decisions were made for all students, instead of recognizing findings of research showing how information is idiosyncratically processed by each learner, interests vary, and consequently classroom life inevitably tends to follow unpredictable patterns.

2.3.4 Constructivist Theory

The work of Piaget, Bruner and Schwab influenced learning and teaching in science immensely throughout the world from the 1950s into the 1970s and some influences are still detectable in science curricula and educational rhetoric. But Jean Piaget's influence was inevitably more profound than the others' though Jerome Bruner certainly had a considerable impact on science education later on with his part in developing ideas about sociocultural dimensions of learning. Piaget argued that knowledge is not merely transmitted verbally but must be constructed and reconstructed by the learner and that children can not learn things until maturation gives them certain prerequisites (Brainerd, 1978). The ability to learn any cognitive content was thus related to an individual's stage of intellectual development. Children who were at a certain stage could hardly be taught the concepts of a higher stage, which was a key conception with respect to Bruner's spiral curriculum (Bruner, 1966). Piaget presented four stages of intellectual development (Wadsworth, 1996) through which learners supposedly passed: The sensori–motor stage (age 0–2), the pre–operational stage (age 2–7), the concrete operational stage (age 7–11) and the formal operational stage (age 11 onwards). He also presented two kinds of learning processes. One was assimilation which implied interpreting new learning experience with existing frameworks. The other kind of learning process was accomodation which meant modifying existing ideas to take account of new learning experiences. The key element of learning was reaching an equilibrium between the two processes. Too much assimilation meant no new learning and too much accommodation caused confusion in thinking.

Although the nature of *constructivism* as a learning theory and as a philosophy in education can be traced through history back to Eastern thought more than two thousand years ago (Pritchard & Woollard, 2010), and its epistemological foundations in Western thought back to Immanuel Kant (Glasersfeld, 1990; Noddings, 1995), the above-delineated conceptions related to assimilation and accomodation assigned Jean Piaget as the essential founder of constructivist theory in education (Noddings, 1995). The essence of constructivist theory is the argument that human beings generate knowledge and meaning from their experiences and consequently learning is influenced by prior experiences and ideas. Compared to behaviourist theory of learning, which assumes that learners acquire knowledge from other sources (teachers, textbooks and other media), constructivist theory assumes that learners construct their own meanings from what they experience. Despite that Piaget is considered the promoter of this theory as it has been conceptualised and applied in education some constructivists have inclined to question his theory of cognitive development (Bennett, 2003) and for example Novak (1978) argued that children's understanding of scientific concepts depends more on the framework into wich they locate the concepts than on the stage they have attained in their cognitive development. Psychologists, e.g. George Kelly and David Ausubel, argued against discovery learning (Bennett, 2003) but embraced what Ausubel described as 'laws of meaningful classroom learning', purporting that new ideas could be efficiently learnt and retained if other related concepts were already available in the cognitive structure. What the learner already knows was considered the most important factor influencing learning. A clear and well organized cognitive structure 'is also in its own right the most significant independent variable influencing the learner's capacity for acquiring more new knowledge in the same field' (Ausubel, 1968, p. 130).

Constructivism has certainly proved to be a 'meta-theory' in education, offering a new paradigm in science curriculum theory (Osborne, 1996), and although its radical version introduced by Ernst von Glasersfeld in the 1970s (Noddings, 1995) has ebbed, its sociocultural version has maintained its impact on science education (Bennett, 2003). The Russian psychologist Lev Vygotsky is considered the architect of *social constructivism* or *sociocultural theory of learning* through his work in the 1930s, despite not being known in Western education until several decades later (Daniels, 2008), many years after his death. His most imperative contribution to science education from 1934 is apparently *Thought and Language* (1986) an exclusive work about scientific thinking and the relevance of language in education (Daniels, Cole & Wertsch, 2007; Carlsen, 2007), where Vygotsky argues that science learning is a process of moving from the linguistically abstract to the concrete, not vice versa; many scientific concepts are invisible or abstract and are hard or even impossible to understand from hands-on experiences. An intriguing conception of Vygotsky's theory was the *zone of proximal development* (ZPD) where he highlighted the difference between the level of actual development as measured by tests, typically IQ tests, that were commonly used in the 1930s, and the level of potential development that a learner could reach in collaboration with teachers and peers utilizing the social support as a tutoring process and thus bridging the alleged 'zone' that exists between what one knows and what one needs to know (Bruner, 1986; Daniels, Cole & Wertsch, 2007). Vygotsky emphasised the importance of culture and language in promoting knowledge and understanding.

The introduction of situated learning, legitimate peripheral participation, cognitive apprenticeships and communities of practice presented by Lave and Wenger (1991) and other sociocultural theorizers (Carlsen, 2007) had important impacts on science education. They claimed that work, interaction, and learning were inextricably linked and issues about language had more to do with legitimacy of participation than knowledge transmission: 'Lerning to become a legitimate paricipant in a community involves learning how to talk (and be silent) in the manner of full participants' (Lave & Wenger, 1991, p. 105). Those who focus on sociocultural forms of science learning argue that the settings ought to feature a process called enculturation (Hodson & Hodson, 1998), where learning is a collaborative and dynamic act and learners acquire values and behaviours that are appropriate or necessary in the culture concerned (Erickson, 2000). Accordingly assessment is typically formative, seen as a continuous, dynamic and interactive process where both instructors and learners are involved in the assessment process; learning and assessment are seen as inextricably linked and not separate processes (Holt & Willard-Holt, 2000). Bruner (1996) focused on the interactions between a learner and a more knowledgeable and experienced individual, and building on Vygotsky's ideas he argued that students could in principle learn more than traditionally expected if they were given appropriate ‘instructional scaffolding’, a temporary framework like building constructors use.

Research evidence about constructivist theories and their application in education affirms and supports most of the main features of constructivism and its significance for science education (Bennett, 2003). It supports the notion that pupils construct their own explanations of natural phenomena and because accepted scientific explanations are often perceived as counter–intuitive, that is they do not make sense in terms of everyday observations, the ideas that students construct tend to persist even after formal instruction. But the terminology about childen’s everyday ideas has provoked interesting controversies about the essence and relevance constructivist theory (Bennett, 2003). Some science educators have considered terms like ‘alternative ideas’ ‘everyday science’ and ‘children’s science’ more appropriate than ‘misconceptions’ or ‘misunderstandings’and thereby recognised them as genuine ideas that children have developed, even though they might conflict with accepted scientific views. Others such as J. McClelland (as cited in Bennett, 2003) contend that such terms, over-emphasising a child-centered ideology, give too much status to children’s ideas and less status to the accepted scientific explanations.

A number of science educators have become critical of constructivist theories and their impact on curriculum development (Kirschner, Sweller, & Clark, 2006; Millar, 1989; Solomon, 1994; Osborne, 1996), among other things on account of the above delineated trends of watering down the status of accepted scientific explanations. Jonathan Osborne (1996) criticised constructivism from an epistemological standpoint for avoiding realism and not paying respect to evidence of research indicating that students vary in their motivaton and preferred learning styles; learning approches offered by constructivist pedagogy may be effective for some students, not all (p. 88). And furthermore Osborne criticised constructivism for confusing the manner in which new knowledge is made with the manner in which old knowledge is learned, assuming that the two are one and the same thing:

> Basically there are two sources of human learning–knowledge that is acquired through sensimotor interaction, that is, by acting and intervening on the world, and knowledge that is acquired through cultural transmission, be it through the popular media or specialized institutions such as schools. Constructivist research has been seminal in exploring the learning outcomes resulting from the first category … in its reaction against didacticism, it has ignored the important issue of how the ideas of science may be told or shown to children, and instead offered a singular pedagogy where meaning is negotiated through a process of cultural appenticeship. (Osborne, 1996, p. 90)

Kirschner et al. (2006) have criticised constructivist-based teaching for advokating unguided methods of instruction. They put discovery learning, problem-based learning, experiential, and inquiry-based learning under the same umbrella as inefficient for novice learners, and suggest more structured learning activities for learners, especially for children with little or no prior knowledge. Scaffolding strategies have also been criticised. Although such strategies have proved effective according to research (Appleton, 2007), some weaknesses have been observed, e.g. Warwick, Stephenson and Webster (2003, cited in Appleton, 2007) questioned whether such strategies functioned as 'scaffold or straighjacket' for higher ability students, denoting that the same learning settings did not fit all students. Despite that scaffolding might be an ideal for the average student, there were other students that preferred more sophisticated strategies and more challenging learning conditions.

2.3.5 Scientific Literacy and STS

The science curriculum is a 'crowded place' (Stinner & Williams, 2003), new content and ideas are constantly being added to it while no one suggests removing anything. Consequently there are many additional issues of concern besides theories of learning and epistemology that have shaped trends in science education. According to Derek Hodson (2003) the 'politicization' of science education is one such issue, because of the socio-economic effects of science and its consequent role in modern society. A Chinese proverb says: 'You can not expect both ends of a sugar cane to be as sweet'; in order to get something, you have to sacrifice something else. The qualities of human life, such as warm houses, cars driven by biofuel, multiple choice of food and beverages, and transportation with goods and people across the world imply sacrifices for the whole ecosystem we call earth. This 'toll' for luxury and pleasure has become a major issue related to science curriculum development. The period 2005–2014 is defined as The United Nations decade of education for sustainable development (ESD), seeking to 'integrate the principles, values, and practices of sustainable development into all aspects of education and learning, in order to address the social, economic, cultural and environmental problems we face in the 21st century' (Unesco, 2010). In the new national curriculum for compulsory education ESD has been declared as one of six fundamental elements of education (MESC, 2011). In 2007 an educational project called *GETA til sjálfbærni – menntun til aðgerða (*e. *ActionESD – Educuational Action for Sustainable Development*) was launched (GETA, 2008), which is a collaborative research and development project with schools from all stages of the Icelandic educational system. Its goals are research and development for promoting awareness of education for sustainable development, and supporting schools that want to develop their curriculum in that direction.

According to the world wide literature on science education, ESD and environmental education have indeed become predominant issues concerning curriculum development in science and other related subjects, and among the strongest arguments for promoting scientific literacy for everyone (Hodson, 2003; Hart, 2007; Jenkins, 2000). According to Hodson (2003) it has to be 'as a means to social reconstruction' because citizens of contemporary society can not escape serious issues like how we plan to achieve a socially just democracy and simultaneously ensure environmentally sustainable lifestyles.

According to Hodson (2003) the science curriculum is unavoidably a key instrument in that respect and hence it can hardly be void of politicization.

Education for sustainable development (ESD) was fairly emphasized in the 1999 national curriculum: ' … promote student's knowledge and understanding of essential goals of sustainable development' (MESC, 1999, p. 9). Although the term 'sustainability' was seldom mentioned in the 1999 curriculum, a study (Jóhannesson, Norðdahl, Óskarsdóttir, Pálsdóttir & Pétursdóttir, 2011) focusing on elements such as values about nature and environment, welfare and public health, action competence, global awareness, economic development and future prospects, revealed a variety of signs and indicators that provided space for teachers and schools to deal with issues related to sustainable development. And before the publication of the 1999 curriculum, environmental and ecological issues had received considerable attention in educational discourse for more that twenty years. Iceland and most other Nordic countries participated for example in the MUVIN project (*Miljøundervisning i Norden*) that started about two decades ago, a project that focused on environmental education (Bergmann, 1995). MUVIN was a target project under the *Nordic Council of Ministers* starting in 1992 focusing on critical discourse about natural resource utilisation, and on ethical and aesthetical issues related to the environment and man's impact on it. At that time the National Centre for Educational Materials (i. *Námsgagnastofnun*) obtained rights to issue a set of learning materials called *Project Wild* and some other materials, and texts and videos related to environmental issues were released in the mid 1990s (Macdonald 1993). Such issues were briefly referred to in the 1989 national science curriculum as well as the 1999 curriculum (MEC, 1989; MESC, 1999) as important strands in all school work. But curriculum development in the 1980s and 1990s, including both policy (intended) and practice (implemented), apparently gave goals and objectives related to the traditional disciplines, such as biology and physics, more punch and priority than values and practices of sustainable development or environmental issues, although learning about the role and nature of science and technology received considerable attention. During the first decade of the new century a revised version, actually an upgrade of the 1999 curriculum, *Aðalnámskrá grunnskóla. Náttúrufræði og umhverfismennt* (Menntamálaráðuneytið, 2007a), offered more emphasis on environmental issues and *nota bene* 'umhverfismennt' (e. *environmental studies)* had been added to the title of the science curriculum. A set of goals under the title of 'living on earth' stressing environmental awareness and understanding of sustainable develeopment had now been intertwined with academic and social goals in biology, physics and earth science with special emphasis on ESD in grades 8, 9 and 10 (ages 13, 14 and 15).

Trends under the labels of 'scientific literacy' and 'STS (Science–technology–society)' as they have been presented in the literature are related to ideas of promoting an education for sustainable development although their definitions vary immensely and the ideologies they build on reach furter back in the history of science curricula. Such trends call for a socially relevant curriculum organized around critical issues like environmental problems and technology, besides focusing on concepts and principles of the old disciplines under certain preconditions. The idea of 'science for all' is part of the same trend (Bybee & Ben-Zvi, 2003).

Douglas A. Roberts (2007) argues that the term *scientific literacy* is a more commonplace term in the literature about science education than *science literacy*. For some authors and professional organisations the distinction is considered unimportant but for others, e.g. the *American Association for the Advancement of Science Education* (AAAS, 1993), there is an unmistakable difference. According to the AAAS science literacy refers to literacy with regard to science *per se*, but scientific literacy refers to properties of literacy (Roberts, 2007, p. 731). According to the research literature (Bennett 2003) the term most commonly used in public school curricula is *scientific literacy*. It concerns the 'ability to understand and discuss scientific matters' where pupils 'draw effectively on the ideas and language of science to contribute to informed discussion'. *Science literacy* on the other hand is 'about the development of talking, writing and reading abilities in science' (Bennett, 2003, p. 148). In other words: 'Thinking is literacy, literacy thinking' as Roberts and Billings (2008) put it, where scientific literacy involves reading, listening, speaking and writing about science in a socio–cultural perspective, while science literacy involves reading, listening, speaking and writing about science from a more theoretical standpoint (Roberts, 2007). But whether or not there is a clear difference between these two terms, there is after all not a clear consensus among scientists and educators about the meaning of literacy in science. Some talk of it as an ambiguous slogan (Fensham & Harlen 1999) while others speak of literacy in science as a key conception in science education.

Robin Millar (1996) sees scientific literacy as the primary goal of school science and supports his argument by referring to the pivotal *Beyond 2000* report in the UK (Millar and Osborne, 1998) and the OECD *Programme for International Student Assessment* (PISA) among other sources. According to Millar, conclusions of all such reports and sources are requirements to promote public understanding and literacy in science for participation and involvement in a democratic society, not merely to train students in science as a preparation for more advanced education in science. So the term scientific literacy 'implies a general education approach for the science curriculum ... [which] suggests that one should begin the design of a program by asking what it is that a student ought to know, value, and do as a citizen.' (Bybee & Ben-Zvi, 2003). Therefore the arguments for public literacy in science must strongly relate to socio-cultural, practical and economic issues. According to Osborne (2000) there are four such arguments:

1. The utilitarian argument, that learners may benefit in a practical sense from learning science.
2. The economic argument, that an advanced technological society needs a constant supply of scientists to sustain its economic base and international competitiveness.
3. The cultural argument, that science is one of the great cultural achievements of our culture – the shared heritage that forms the backdrop to the language and discourse that permeate our media, conversations and daily life.
4. The democratic argument, that (because) many of the issues facing our society are

> of a socio-scientific nature … a healthy democratic society requires the participation and involvement of all its citizens. (Osborne, 2000)

The second argument above, the economic argument, does indeed apply to further science education rather than what every citizen should know, value, and be able to do. But bearing in mind that compulsory education must at least partly rest on this argument accounting for the approximately 20% of students that presumably will attend further science education later on (Fensham, 1985), and also bearing in mind the meanings of science literacy on the one hand and scientific literacy on the other as discussed above, this argument stands as part of literacy. Other arguments, more or less overlapping with the others, are the political, the social, the individual and subject maintenance arguments (Sjøberg, 1990; Fensham, 1988), and consequently are claimed to be included in the official curriculum.

The idea of scientific literacy has been known in the science education literature for at least 50 years (DeBoer 1991). But viewing science and technology as socially embedded enterprises received a sharper image than ever before around the 1970s under the rubric of *science–technology–society (STS)*. According to its advocates, science education was to become humanistic, value-oriented, and relevant in a societal, and environmental sense (DeBoer 1991). The humanistic perspective embraced the idea that, besides knowledge and intellectual skills, human abilities and characteristics comprise feelings, emotions and the need for personal and meaningful experiences. The values dimension involved the need for all citizens to be concerned with controversial issues and dilemmas related to science and technology. Environmental awareness was without doubt the greatest force behind the STS-movement. Under the approach of an STS-curriculum students were not only supposed to appreciate the value of science and technology for society, but also have an open eye for their limitations and be critical (van den Akker, 2003, p. 428) which meant, as Hodson (2003) put it, politicizing the science curriculum with respect to environmental issues. Consequently the idea behind STS was that learners should become better informed and critically oriented decision makers in everyday life situations, so the STS-movement was closely associated with the idea of *scientific literacy* and also with another slogan that mushroomed in the literature around 1980: *Science for all*.

Scientific literacy was not presented as a key concept or 'big idea'in the official Icelandic curriculum, 'aðalnámskrá', until 2007. But trends towards the idea can be traced at least back to 1968 (ME, 1968):

> … the main purpose of physics and chemistry instruction in lower-secondary schools is to prepair students for living and working in a changing society so that the ordinary citizen will neither be frightened by science nor worship it in blindness. He should realize that the cause of most natural phenomena is normal and that the application of scientific working methods is important in order to understand and have some control of our environment. (ME, 1968, p. 8; English translation as cited in Macdonald, 1993)[2]

[2] Nefndin telur, að megintilgangur kennslu í eðlis- og efnafræði á gagnfræðastigi sé að búa nemendur

The idea of 'science for all' and science being taught and learned through all grades in the compulsory school first appeared in the official Icelandic science curriculum published in 1989, where subject matter was specified for all grades, from 6 years old to 16, with generally stated goals. 'Students attending compulsory education are entitled to studying natural science, both as a preparation for life and work and as an essential part of their personal development. Studying science cultivates incorrupt curiosity, apperception towards the environment, critical evaluation of logic, a more focused viewpoint on man's position in the world, and respect for important elements of the cultural heritage' (MEC, 1989)[3].

2.3.6 Science for All

Glen S. Aikenhead (2006) has argued that in a diverse world it appears as a paradox that science education in public schools has traditionally 'served an elite world, not a diverse world' (Aikenhead, 2006, p. 11). Nevertheless the idea of science education for all students has emerged gradually, but slowly, throughout the twentieth century (Harlen, 2000; 2006). Science educators and scholars, such as Lancelot Hogben in the 1930s (cited in Fensham & Harlen, 1999) and Nathan Isaacs in 1962 (Harlen, 2006) had argued that science education could not only be regarded as a secondary school endeavour focusing on formal education in science as a preparation for science-related professions: 'science in some sense now has claims to form part of the very ABC of education' (Isaacs, 1962, cited in Harlen, 2006) and Harlen continues reflecting on Isaacs' writings where he pointed out that this literacy was needed by all, as a means of preventing a 'cultural cleavage' between the 'scientific community and the non-scientific rest of us'.

During the 1980s and 90s the idea of science education for all students spread worldwide, mainly because UNESCO and many countries thereafter celebrated new goals for school science under the label of *science for all* (UNESCO, 1983; National Science Foundation, 1983; Science Research Council of Canada, 1984; The Royal Society, 1985) and later (1989/1993) the American Association for the Advancement of Science (AAAS) defined literacy goals for all citizens in science, mathematics, and technology through *Project 2061*. But there were questions that needed to be asked and answered such as:What science were the 'non-scientific rest of us' supposed to learn, using Nathan Isaacs' wording? And in what ways?

Peter Fensham (1985; 1986/1987; 1988; 2004; Fensham & Harlen, 1999) has covered this

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undir líf og starf í breytilegu þjóðfélagi, svo að hinn almenni borgari verði hvorki hræddur við vísindi né blindur dýrkandi þeirra. Honum ætti að vera ljóst, að flest náttúruleg fyrirbæri eiga sér eðlilega orsök og að beiting vísindalegra vinnbragða er mikilvæg til þess að öðast skilning og nokkra stjórn á umhverfi okkar.

[3] Nemendur í skyldunámi eiga rétt á að kynnast náttúruvísindum sem verða jafnt undirbúningur undir líf og störf sem ómissandi þáttur í almennum þroska þeirra. Náttúrufræðinám þroskar heilbrigða forvitni, skynjun á umhverfi, gagnrýnið mat á rökum, gleggra sjónarhorn á stöðu mannsins í heiminum og virðingu fyrir mikilvægurm hlut mennignararfsins.

topic comprehensively, where he makes a clear difference between science for future scholars and scientists (about 20% of an age group according to Fensham) on the one hand and science for literate citizenry on the other (about 80%) who will not necessarily continue with formal education in science. Considering the concern and intention behind *science for all* Fensham (1985, p. 425–426) stated that it should be offered all pupils through primary, lower secondary and upper secondary schooling with emphasis on personal and social issues, broad themes and topics relevant to learners, good balance between knowledge, application of knowledge, practical skills, problem-solving and understanding of the nature, evolution and limitations of science. Finally: 'Assessment should recognize both prior knowledge that the learners have of scientific phenomena and their subsequent achievements in all the various sorts of criteria for learning that make up the curriculum.' (p. 425).

But there are question marks over the ability of one science curriculum to meet the needs of all pupils (Bennett, 2003). According to the important report *Beyond 2000* (Millar & Osborne, 1998) a traditionally designed science curriculum for pupils planning on to further study of science does not align with a curriculum for all students. It does not meet the needs of science education for all students, i.e. an education about science rather than learning facts and theories of science. All students, whether they continue with formal science education or not, need to learn how scientific and technological knowledge is applied and how controversial decisions are made with respect to science and technology. But as Fensham (1995) also suggested Millar and Osborne conclude that there should be additional modules for scientifically oriented students covering more traditional content. The Twenty First Century project mentioned earlier, a pilot study commissioned by the English Qualifications and Curriculum Authority (QCA), is an attempt for meeting such needs of covering scientific literacy on the one hand and science as preparation for advanced scientific studies on the other (Millar & Osborne, 2006).

2.3.7 Reflections

Despite promising trials and deliberative approaches, e.g. *The Twenty First Century Science* in England and the *Algemene Natuurwetenschappen* in the Netherlands, there are major issues that puzzle and evoke concern among science educators and science curriculum developers. To conclude this coverage on the science curriculum it is proper to reflect on Millar, Leach, Osborne and Ratcliffe's views (2006) about the major issues that concern science educators according to research at the beginning of the new century according to research, and connect them with the above.

Their first and second issues of concern pertained to decreasing motivation of learners towards science, affirmed by *falling numbers of students who choose to study science* beyond the age when it is a compulsory element of the curriculum and the *falling enrolment in more advanced science courses and negative attitudes towards science as a school subject*. Science appears to be seen as difficult, as offering little scope for creative work and not valuing students' views and ideas. There is a strong argument that these two issues of concern have to do with the problem De Vos and Reiding (1999) reported on how ‘extremely difficult [it is] to escape from the shadows of the science teaching tradition’, denoting that the content and pedagogy oriented towards the academic disciplines has prevailed, but to a similar extent failed to engage students with further science learning (Osborne & Dillon, 2008). Accordingly teachers, educators, curriculum developers and policy makers need to deliberate on what sort of science content should be offered to whom, what should be included and what should be excluded in the compulsory curriculum, whether there should be one science course for all students attending compulsory education or optional programs, to what extent should the science curriculum be academic, to what extend practical, to what extent socially oriented, and to what extend vocational?

The third issue of concern was about students reporting a *disjunction between the science they are taught in schools and the more interesting science that they experience elsewhere*, which indicates the need to orient school science for all students more towards scientific literacy. Among the most striking evidences on the failure of the curriculum reform in the 1960s were the abstract nature and theoretical sophistication of the curriculum, ignorance of science in the social world and everyday life of students and little effort in developing students’ interest in studying science (Hurd, as cited in DeBoer, 1991). And the idea of encouraging pupils to be scientists and the conceptual demands of the discovery science courses proved to be well beyond the ability of average students (Bennett, 2003). Presumptively educators need to address this problem and ask to what degree the spirit of the curriculum from the 1960s is still functioning in science education. Furthermore, they need to ask what kind of science is ‘the more interesting science that they experience elsewhere’; are such goals and content relevant and valid as part of the intended curriculum? Who has the knowledge and power to settle all contention or uncertainty in question?

The fourth concern was that *science-related issues that arise in everyday life refer to learning goals that are not well defined or strongly emphasised in the curriculum*, not validly assessed, and hence not prominent in teaching programs. This issue should certainly be of great concern because it has to do with science literacy, STS and the learner’s own ideas of science and its relevance in daily life. It relates to the fundamental questions of what students ought to know, value, and be able to do as enlightened citizens (Bybee & Ben-Zvi, 2003), so that ‘they may become more astute “consumers” of scientific information’, as Millar et al. put it (2006, p. 20). If learning goals and assessment in this area are not defined well enough or emphasised sufficiently, then educators must discuss how this problem can be resolved.

The fifth issue was the tension between *providing science education appropriate for all future citizens whilst also meeting the needs of those who choose to continue their study of science* to more advanced levels. Two projects designed to resolve this tension were discussed above, i.e. the *Algemene Natuurwetenschappen* in the Netherlands (De Vos & Reiding, 1999), and *The Twenty First Century Science* curriculum in England (Nuffield

Curriculum Centre, 2010). But as argued before it appears not to be sufficient to offer different programs, on the one hand science to all future citizens for understanding and functioning in everyday life and on the other science for further education in science and future specialist jobs. Educators need to consider how both of these programs should be presented, to what extent the goals and content should be academic, to what extent practical, to what extent socially oriented, to what extent vocational, and to what extent integrated with other fields of learning.

The sixth issue was that research indicates that *students acquire little understanding of fundamental science concepts, retain prior non-scientific ideas, and fail to integrate the taught ideas into a coherent framework*. This was among the great concerns that Jerome Bruner (1966) expressed almost half a century ago. Integrating the taught ideas meant placing details into a structured pattern according to Bruner: ‘Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structured pattern, it is rapidly forgotten.’ Another matter of concern related to the belief that students ‘fail to integrate the taught ideas into a coherent framework’ is the competence of the teacher to organize curriculum and instruction of science to help students put things into a coherent framework. Bruner also made a point of this in *The Process of Education* (1966): ‘It takes no elaboarate research to know that communicating knowledge depends in enormous measure upon one’s mastery of the knowledge to be communicated’ (p. 88). Bruner also emphasised the fact that learning the content of the subject was not adequate. Teachers need to know the methods and aids to teach the subject. Being a compulsory school science teacher denotes having insight into the contents of several ‘academic’ disciplines and knowing how to promote students‘ understanding and integrate the taught ideas into a coherent framework with respect to their varous prior ideas. In this respect educators need to take into consideration ideas of transforming content knowledge of academic disciplines into forms suitable for learning and teaching in classrooms, referring to Shulman’s conceptions of *content knowledge*, *pedagogical content knowledge* (PCK), and *curricular knowledge*.

The seventh and last concern Millar et al. put forward was that *tests used at all levels from schools to international surveys tend to over-emphasise recall of discrete ‘bits’ of knowledge, rather than understanding of worthwhile bigger ideas and fundamental concepts*. According to research that they cite, it is not certain that students, who score well on such tests, can give adequate answers to questions probing their understanding of basic ideas. This issue relates to a problem that Samuel Messick (1994) attracted attention to, namely consequential validity. He argued that particular uses and interpretations of assessment results required evaluation of its intended and unintended consequences. Assessment may have either positive or negative consequences. It may improve motivation and encourage good study habits. But research shows that it may also have unfavourable effects in some important areas of learning, and it affirms that learning goals that are not well defined or strongly emphasised in the curriculum are not validly assessed, and hence not prominent in learning and teaching programs. Accordingly the consequential validy of assessment affects all aspects of the science curriculum, whether the focus is on traditional science, scientific literacy, STS, science for all or what is of most concern: An over-crowded curriculum with an amalgamation of all these aspects involved.

2.4 School Science in Icelandic Compulsory Education

Reviewing and analysing the science curriculum as it transforms over time is in effect a study of the history of education. Otherwise stated, this is a historical study where the literature is part of the sources of data for research (cf. Cohen & Manion, 1994). Data analysis and interpretation focuses on the 'historical transformation' of the science curriculum in Iceland with respect to the international literature. As an example when the Icelandic national curriculum in force from 1976 to 1989 was reviewed and analysed in this study, it was done from a broader perspective taking into account discourse and ideas leading up to curriculum development during that period.

2.4.1 School Science: Not a Monolithic Entity

Ivor Goodson (1994, p. 42) called attention to three implications, that he considered important for studying the history of the science curriculum. First that subjects like school science 'are not monolithic entities but shifting amalgamations' of traditions and views. The history of school science in Icelandic compulsory schools has indeed featured shifting amalgamations concerning the rationale, aims, contents and methods of science education. An ambiguity about titles and terms reflects this well (Macdonald, 1993). The terms 'science' and 'natural science' were seldom observed in Icelandic educational rhetoric during the twentieth century. Official curriculum guides and textbooks generally bore titles like 'nature studies' (i. *náttúrufræði*), botany (i. *grasafræði*), zoology (i. *dýrafræði*), physics (i. *eðlisfræði*) and later biology (i. *líffræði*).

An interesting schoolbook on physics by Johann Georg Fischer was translated into Icelandic from Danish and published in 1852. It defined 'nature studies' as the study of two kinds of natural bodies. First there was a study of the dead natural bodies (i. *dauðir náttúrulíkamir*), the part of nature that was insentient. Secondly there was the study of living natural bodies, i.e. the part that was sentient. The author presented physics (i. *eðlisfræði,* d. *fysik*) as the essence of nature studies (*eðli = náttúra* as *physis = nature*) since it explains 'the forces of the dead bodies' and 'the forces of the living bodies to the extent that they depend on the same universal laws as the other organisms' (Fischer, 1852, p. 2). A distinguished Icelandic geophysicist, Leó Kristjánsson (Kristjánsson, n.d.), appointed this book as one of the most noteworthy of schoolbooks on physics published in Iceland.

Nature studies had indeed multiple meanings in Icelandic education from one time to another, sometimes covering the whole range of biology, physics, chemistry and earth sciene or as frequently happened, only the study of living natural bodies. This has turned out to be problematic because 'náttúrufræði' has been used as an umbrella conception in the official curriculum for natural science in its broadest sense, while by many scholars and layman it been conceived of as the study of life and living things exclusively. During the twentieth century many official documents discussed 'náttúrufræði' and 'eðlisfræði' as two distinct subjects (cf. Elíasson, 1944), 'náttúrufræði' being the study of 'living natural bodies' and 'eðlisfræði' being the study of 'dead natural bodies'. Up to the present day studying the part of nature that is insentient has by many been conceived as unconnected to life science, and received other labels as well, like 'real subjects' (i. *raungreinar*), 'real science' (i. *raunvísindi*) or simply 'physics and chemistry'. Furthermore, as elsewhere in the world, the science curriculum in Iceland has kept expanding into a multiplex field with various perspectives and emphases, a mixture of different kinds of visions and educational aims, rather than rigidly defined school subjects (cf. Donnelly, 2006). Consequently it has become a world of different perspectives on 'the forces of the dead bodies' and 'the forces of the living bodies' and how they depend on the universal laws and how they play an essential role in our social and cultural lives.

2.4.2 School Science: Utilitarian or Academic Goals?

The second point that Goodson called attention to concerned the evolution of school science from promoting pedagogic and utilitarian purposes to adjusting school science to contents and methods of academic disciplines, 'with ties to university scholars' (1994, p. 42). Ideas about 'science for the people', 'the science of common things' (Layton, 1973) and 'life adjustment science education' (DeBoer, 1991) were intriguing in Icelandic educational discourse during the first half of the twentieth century (Elíasson, 1944; Finnbogason, 1903). According to Finnbogason (1903) one of the most important curriculum areas was 'nature studies because of its value for human life … schools need to single out issues that best fit the purpose of promoting cognitive development and at the same time provide knowledge that best serves learners in their daily lives' (p. 77-78). Notably, according to Finnbogason 'nature studies' referred to both sentient and insentient phenomena. But as in other Western countries major changes occurred in Iceland during the 1960s, i.e. 'when the first large-scale science curriculum development activities were initiated' (van den Akker, 2003, p. 423). The changes were inspired by the same kind of rhetoric as elsewhere. Scientists and politicians complained that our students were falling behind in 'real science' and the curriculum in 'nature studies' was critisised for emphasizing 'practical knowledge' maintaining a 'stagnant society': 'In the United States and United Kingdom an extensive work has been done in creating new materials in real science, materials that meet the emerging demands that our modern society requires' (ME, 1968, p. 14). Here the authors called for the academically oriented science curricula that flooded science education in the Western world during the 1960s and 1970s, stressing the idea that engaging in real scientific activities like scientists did would be the most effective way to learn science.

2.4.3 School Science and its Space within the Curriculum

The third point that Goodson identified was a conflict between subject areas over status, resources and territory. Indeed there have been concerns about the limited space of science in the official curriculum and its inefficacy. As an example an OECD report (OECD, 1987) affirmed that Icelandic curricula differed markedly in the balance of subject areas from what was common in other countries: 'The crux of this difference is in the large amount of time devoted to language learning, both of the mother tongue and of two foreign languages, which of course limits other areas such as social studies, history beyond Icelandic history, and science' (p. 23). According to the *Education at Glance* report (OECD, 2011) instruction time devoted to science for 12-14 year olds in Iceland was 8% of total compulsory instruction time while the OECD average was 12%, in England it was 14% and Finland 17%. Additionally there are some indications that physical science has received less attention than life science (Macdonald, 1993; Appendix II, Article IV), and two officially appointed committees (ME, 1968; 1972), identified trends in Icelandic schools that constrained physics education, mainly due to textbook learning like in most other school subjects where reading and reciting schoolbook contents featured the style of learning, the main emphasis being memorising contents of the schoolbooks, 'to be able to deliver the text from the book and its figures in detail to solutions and answers on tests, reciting passages from the books or computing certain types of mathematical problems' (ME, 1972, p. 5)[4]. The authors suggested that the emphasis should move from transmitting superficial knowledge to learning contexts that promoted understanding of concepts and methods through hands-on learning and experimentation. The results of the TIMSS study (Beaton et al., 1996) indicated that the physical part of science education appeared vague and seemed to receive less concentration in Icelandic curricula than in other countries. Finally it is interesting to note that for the past two decades more and more primary school teachers have studied science during their teacher education in Finland (Sahlberg, 2011) while at the same time an interest in science has declined among Icelandic student teachers.

2.4.4 School Science and the Preparation of Teachers

Goodson also drew attention to the tendency of conceiving science subjects like biology and physics as 'hard science' with an academic status and thus featuring the control of university scholars over the curriculum, a tendency also well known in Icelandic science education. It called for knowledge that Shulman and his associates (Shulman 1986; 1987) emphasised on how teachers transform their previously learned content knowledge of academic disciplines into forms suitable for learning and teaching in classrooms. Some Icelandic studies indicate that Icelandic teachers are poorly prepared to teach academically oriented science with respect to content knowledge (CK) and pedagogical content knowledge (PCK). In a study conducted for the Reykjavík Educational Centre (i *Fræðslumiðstöð Reykjavíkur*) (Þórólfsson & Birgisdóttir, 1998; Appendix III, RCE II) science supervisors, i.e. teachers who's major roles were supervising learning and teaching of science in their schools, reported that teachers' weak self–confidence, poor CK/PCK and lack of motivation towards physics and chemistry, were among the most

[4] …að geta skilað texta bókarinnar og myndum sem nákvæmast á prófi, endursagt úr henni kafla eða reiknað ákveðnar tegundir dæma.

tangible constraints in science education (p. 11 & 24). Furthermore, the spectrum of teaching styles found among Icelandic science teachers appeared narrow and poor. According to Sigurgeirsson's research (1992) previously defined goals, content, concepts or skills proved ambiguos in science learning and teaching, while teachers turned out to be overly contingent upon written materials; 73% of their science teaching time was dedicated to work with textbooks. Furthermore, as indicated by the TALIS–report (OECD, 2009), Icelandic teachers seem to lack academic preparation in science compared to other OECD countries. Macdonald (1993) reported that in the 1980s and the 1990s most of those who taught science were trained to teach, but only a quarter of them were trained to teach science, and most of them only in biology, not in physics or chemistry. In the beginning of the second decade of the 21st century the situation became even more serious regarding teacher preparation in science. In 2011 only 8 out of 213 B.Ed candidates chose natural science as their main area (H. Arason, personal communication, September 13, 2012).

According to this one may conclude that Icelandic compulsory school students receive poor science education resulting in lower scores in international surveys such as TIMSS and PISA. Some of the results from the 1995 TIMSS study support and illuminate the view that Icelandic students lacked knowledge and understanding of phenomena like physical needs and lifestyles of living organisms. According to the TIMSS results (Beaton, et al., 1996) Icelandic students scored well above the average when asked to determine the age of a tree by counting its annual rings, which may be explained by more emphasis on schoolbook use and recitation in life science. But it is worth examining further that only 7% of Icelandic 12 year old students and 13% of 13 year old students were able to explain the importance of light for an ecosystem (Beaton, et al., 1996). The mean score in the whole TIMSS study was 26% for age 12 and 33% for age 13. An understanding of the differences between a cell, a molecule and an atom was found among 9% af Icelandic students at age 12 and 12% at age 13, while the mean scores were 21% and 32% in the whole study. The OECD PISA results indicate that achievement in science decreased from 2000 to 2006 compared to other countries. Of 31 countries participating in PISA from the beginning in 2000 and through 2003 and 2006, 35.5% scored above Iceland in 2000, while 45.2% scored above Iceland in 2003 and 51.6% in 2006 (Halldórsson, Ólafsson & Björnsson, 2007).

2.4.5 School Science and Research

A small society like Iceland has limited capacity to sustain large-scale educational research. Nevertheless some Icelandic educators have been prolific in carrying out science education research (Bjarnardóttir, Símonardóttir & Garðarsdóttir, 2007; Macdonald, 1992, 1993; Macdonald et al., 2006-2007; Sigurgeirsson, 1992; Sigþórsson, 2008; Þórólfsson, 1998) revealing some interesting trends in Icelandic science education. The Intentions and Reality (IR) project (i. *Vilji og veruleiki*) (Macdonald et al., 2006-2007) comprised a collection of interesting information on science education, including technology and innovation education, from schools in three different areas in Iceland, the east part, the west part and urban southwest. It included interview data from principals, teachers and pupils in lower-secondary grades, as well as on-site observations, classroom observations and assessments of teaching conditions.

Like research from larger societies, Icelandic research reflects some important messages. The first message worth identifying includes the need to involve teachers and others concerned with classroom practice in curriculum development and discussion about the organization of science learning and teaching. Innovative ideas must indeed sound relevant to teachers, appear practical and approachable to implement. The second message concerns the purpose of science education, the need to serve two main goals in science education, i.e. preparing a minority of students to become future scientists and simultaneously educating the majority of students in general science and thus promoting scientific literacy among future citizens not planning on science educaion. A third message involves problems related to decreasing interest in science and falling enrolment in advanced science courses, which is closely connected with understanding how people learn and thus a need to take pedagogical theories into consideration. It also relates to epistemology and our ideas of knowledge, information and communication. A fourth message from research worth mentioning (cf. Marsh, 2006; Millar, Leach, Osborne & Ratcliffe, 2006) is the fact that the gap between 'official' school knowledge and real-world knowledge to which students have access through ICT increases constantly. Finally and principally there is the problem of poor science teacher education. The status and quality of science instruction appears in need of improvement. This problem seems to concern weak interest and motivation among compulsory school teachers towards science as a school subject, as well as weak content knowledge (CK),and pedagogical content knowledge (PCK).

2.4.6 Reflections

To conclude this brief overview of the context of the science curriculum in Iceland an interesting phenomenon well known in international research in a wider context should be noted. This intriguing theme found in many studies (Bjarnardóttir, Símonardóttir & Garðarsdóttir, 2007; Macdonald, 1992, 1993; Sigurgeirsson, 1992; Sigþórsson, 2008; Þórólfsson & Birgisdóttir, 1998) indicates that there are contradictions in what teachers consider as important aims in science education on the one hand and what they actually practice on the other hand. According to these findings teachers consider topics like encouraging protection and conservation of nature and the environment, knowing living things, interconnections in nature, preparing students for daily life, and promoting healty habits, among the most important aims of science. But curriculum guides and syllabi from schools indicate that science teachers seem to focus on knowledge and skills from schoolbooks they prefer to teach. Indeed it 'seems as if teachers are aware of and value the environmental aspect of science education in the national guidelines, but still tend to base the formal purpose of science on the basis of the materials selected, and the knowledge and skills developed in them' (Macdonald, 1993, Status report A, p. 30–31).

Perhaps this suggests that most of the attention that environmental issues and the like receive are rhetorical, i.e. most teachers give only ‘lip service to these ideas while continuing older practices’ as Arthur Zilversmit (1993) described educators’ attitudes towards progressive education in the last century. These findings are even more intriguing in light of the PISA results from 2006, where Iceland was among the lowest achieving countries with respect to students’ performance and awareness of environmental issues (OECD, 2007, p. 80). When explored in context, all these findings indicate some missing links in the curriculum context. To achieve aims such as an awareness of environmental issues, the cognitive aspects of science can hardly be ignored:

> There is no point whatsoever in encouraging students to conserve nature, have healthy habits and use natural resources sensibly, if they do not know something about nature and themselves, and understand the implications of what they have learnt. Students will never understand interconnections in nature if they know nothing about what is being connected, such as energy in all its forms (heat, light, sound) and the needs and lifestyles of plants and animals. (Macdonald, 1993, Final report F, p. 9–10)

CHAPTER 3
MAIN FINDINGS

This thesis focuses on the following questions:

- *What characterised the transformation of the science curriculum for Icelandic compulsory schools in force from 1960 to 2010?*
    - *From a diachronic perspective?*
    - *From a synchronic perspective?*

Efforts to answer these questions are to be found in the five articles it is based upon (See Appendices I & II) and other data presented in this chapter. The following subsections include a focused brief on the main findings. As in the articles the findings are in some cases deliberately interpreted here, and put into further context in the Discussion chapter.

3.1 Transformation 1960 to 2010: A Diachronic Perspective

The diachronic perspective (Appendix I, Articles I - III) denotes how the curriculum has evolved over a period of fifty years, 1960 to 2010. The official curriculum guides for school science were analysed with respect to curriculum ideologies and theories about educational change (Articles I - III), focusing on rationale, aims, content, and role of those concerned (cf. van den Akker, 2010). The official written curricula issued in 1960 (in force 1960-1976), 1976 (in force 1976-1989), 1989 (in force 1989-1999) and 1999 (in force 1999-2010) were analysed. First, the position and role of learners, teachers, subject matter and milieu was observed and second the extent to which they adhered to a content/product model on the one hand or a process/development model on the other hand.

3.1.1 Fifty-year Transformation Analysed on a Rating Scale

The contents of the curriculum guides were analysed on a five-point rating scale (Article I). As figure 2a indicates the position of the teacher and instruction weakened progressively from 1960, when it was judged between strong and very strong (4.5 on a 5 point scale), to weak (2) in the 1999 curriculum. The position of the learner and learning (Figure 2b) became stronger on the other hand, from being weak (2) in the 1960 curriculum to becoming very strong in the 1989 curriculum and between moderate and strong (3.5) in the 1999 curriculum.

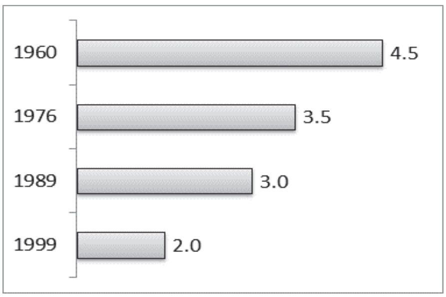

Figure 2a. Position of teacher and instruction in the official science curriculum 1960 – 1999. Assessed on a 5 point rating scale.

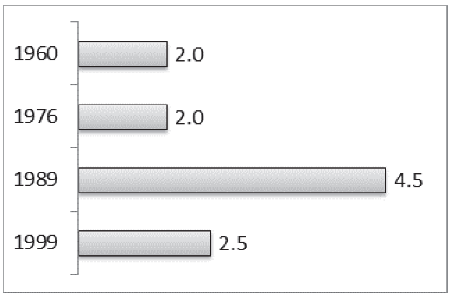

Figure 2b. Position of learner and learning in the official science curriculum 1960 – 1999. Assessed on a 5 point rating scale.

The role of subject matter was judged strong or very strong in 1960, 1976 and 1999, but weak in the 1989 curriculum.

As discussed in Article I, curriculum theorisers often differentiate between a *content–product*-oriented curriculum and a *process–development*-oriented curriculum. A *content–product*-oriented curriculum focuses typically on facts to know and skills to master (Article I). Knowledge is conceived as an end to proceed towards, a product to be manufactured. A *process–development*-oriented curriculum on the other hand places the learner at the centre, viewing cognitive development and learning experiences as significant aspects of education rather than prescribed objectives and contents.

Figure 3a. To what extent was the official science curriculum 1960 – 1999 assessed as *content-product* oriented? Assessed on a 5 point rating scale.

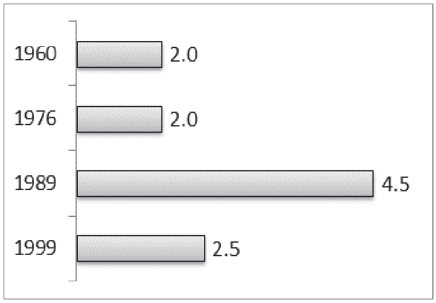

Figure 3b. To what extent was the official science curriculum 1960 – 1999 assessed as *process-development* oriented? Assessed on a 5 point rating scale.

As figure 3a confirms the 1960 and 1976 curricula were assessed as strongly *content–product*-oriented, while the 1989 curriculum was assessed as very weak in that respect. All the curriculum guides were judged weak or less than moderate with respect to *process–development*-orientation except the 1989 curriculum which was assessed between strong and very strong (4.5) in that respect.

3.1.2 An Era of Status Quo Politics

The period from the mid-1940s to 1970 has been defined as an era of status quo politics in Icelandic education (Árnason & Baldursson, 1994; Edelstein, 1988; Kjartansson, 2008), featuring a transmission-of-knowledge pedagogy and curriculum ideology defined as subject-centred.

The **1960 curriculum** was analysed as promoting the position of teachers and instruction rather than the position of learners and learning (Articles I & III). It emphasised the role of subject matter rather than milieu, with some exceptions though. The curriculum was more content-product oriented than process-development oriented. Consequently the social efficiency ideology (cf. Schiro, 2008) was detected to a considerable extent, to some extent the scholar academic ideology and to a small extent the learner centred ideology. Teaching the old nature studies such as zoology and botany featured conditioning of behaviour, where learners were to be ‘shaped’. Assessment did not receive much attention in the 1960 curriculum text though it could easily be understood as gathering data about knowledge and understanding acquired from textbooks (product). The social reconstruction ideology was negligible on the other hand. With regard to *scientific literacy* the goal was primarily *acquiring knowledge and skills to function in society*.

Interestingly each chapter in the 1960 curriculum had a supplement section with ideas about the role of teachers and learners. The Nature Studies chapter had a supplement section with recommendations reminiscent of constructivist ideas, such as relating new knowledge to prior experiences, stressing hands-on learning, and suggestions that students should discuss and present their work orally and in writing. Furthermore in the Local Studies section children's knowledge about their environment was emphasised, and: '[In Local studies] children are brought into a world ... not in such a manner that they feel they are being instructed about it, but rather as if life itself unfolds for them through their own activities and observations.' (ME, 1960, p. 28). Thus the 1960 curriculum featured theories of child development and consequently the learner-centred ideology was detected, so the curriculum was not solely under the influence of content-product ideologies.

3.1.3 Profound Reform Efforts

Six years after the 1960 curriculum was issued a governmental agency, the *Department of Educational Research* (DER) (i. *Skólarannsóknadeild*), was established. *Inter alia*, DER was assigned to conduct research and development in Icelandic public education, including curriculum development, organisation of learning and teaching, revision of subject matter and evaluation, including the standardization or centralization of assessment (ME, 1988). This was the beginning of a period of profound reform efforts, surfacing like a sudden eruption in Icelandic public education.

Among dramatic change efforts in the DER were the 'new math' and 'new science'. **The 'new science' curriculum was issued in 1976**, an academically directed curriculum, literally expecting teachers and students to think and act like real scientists. The science section was to be issued in two booklets, Physics and Chemistry (i. *Eðlis- og efnafræði*) and Biology (i. *Líffræði*), but the biology booklet never reached publication. The focus was on knowing and understanding basic ideas in physics, chemistry and biology, featuring general aims and to a certain extent measureable objectives. The physical science curriculum reflected scientific purism, with negligible connection to student's everyday milieu.

The curriculum of 1976 was abstract in nature, conceptually and cognitively sophisticated, and detached from the natural milieu of students. The role of subject matter and scientific experimenting predominated at the price of natural milieu of learners. Despite an emphasis on 'student's activity in seeking knowledge … [rather] than acquiring bits and pieces of knowledge' (ME, 1976, p. 6-7) the curriculum was analysed as *content-product* oriented rather than *process-development* oriented and the *position and influence of the teacher* received more attention than the *position and influence of the learner* regarding the learning process.

Accordingly the 1976 curriculum focused on instruction (as prescribed by authorities) rather than learners and learning activities, but for activities where pupils were supposed to play scientists. The curriculum was analysed as adhering to *scholar academic ideology* (cf. Schiro, 2008) most predominantly, and to a negligible extent other ideologies. In light of *scientific literacy* the goal was *adopting the canonical discourse of the discipline, sanctioned by academic scholars* (cf. Article I).

3.1.4 New Progressivism and Unstable Political Conditions

The period from 1970 to 1989 was indeed a period of intensive transformation featuring conflicting curriculum ideologies. In spite of the DER reformers' ambitious ideas of improving the school system, calling for intellectual rigour through learning the academic disciplines, they seemed to have 'underestimated the complexity of change processes in education' (Edelstein, 1987) and furthermore they probably did not foresee the unstable political conditions waiting ahead. **The 1989 science curriculum** reflected a profound ideological change from the preceeding 1976 curriculum. It was the first official curriculum in Iceland to materially emphasise the *learner-centred ideology*, and it certainly reflected familiar ideas from the past. A focus on students' milieu and social contexts was reminiscent of conventional pedagogy of the progressive era in the first decades of the twentieth century. Ravitch (1983) referred to this renewed focus as the 'new progressivism'.

The curriculum of 1989 was assessed as open-ended, focusing on transferring power to teachers as professionals to select content and organise learning according to the context and needs of learners. They were urged to intertwine natural science with other subjects and thus focus on thematic learning. The boundaries between subjects were to be 'blotted out' (MEC, 1989, p. 32) and teaching and learning were supposed to reflect 'whole child development'. Learners were conceived of as self-actuated makers of meaning, with specific individual needs according to their overall development. Science learning was seen as acculturation into a milieu friendly environment, stressing each learner's interests, intrinsic motivation and respect towards natural phenomena. The emphasis was on enquiry learning and collaborative learning stressing learners' examination of their own natural milieu.

Hence the 1989 curriculum was analysed as promoting the role of learners and learning milieu rather than subject matter and direct instruction. The curriculum was assessed as *process-development* oriented, not *content-product* oriented (Article I). Consequently the curriculum developers and policy makers were presumed to adhere to *learner centred ideology* (cf. Schiro, 2008) and to some degree social reconstruction ideology. In light of *scientific literacy* the goal was *promoting growth of learners and their critical understanding of science and its role in their lives*.

3.1.5 A Synergy of Different Ideas

Political conditions in Iceland were unstable during the 1980s and 1990s. But during the last decade of the twentieth century and until 2008, social and political discourse and practice in education was mainly characterised by neo-liberalist views here as in other Western countries at that time (Ball, 2007). The focus was on accountability, measurement and standardised testing. Synchronously educational policy featured decentralisation, individualism and competition. Liberal conservatives governed the Ministry of Education, Science and Culture for seventeen years from 1991. A **new national curriculum was issued in 1999** comprising 12 booklets for compulsory education, covering almost one thousand pages of detailed aims and objectives. It was introduced as the 'new' curriculum featuring a 'new' rationale for a 'new' century.

The 'new' message appeared as behaviouristic, objectives-driven curriculum, featuring clear benchmarks to direct both instruction and assessment. But the 1999 curriculum was also influenced by another 'new' kind of ideology; it argued for constructivist ideas about learning and teaching. An emphasis was placed on solid knowledge and understanding of the disciplines of science, physics, chemistry, biology and earth science, their nature and their role within modern society. Knowledge of principal laws was considered important, along with certain skills in scientific working procedures (MESC, 1999, p. 7), while there was also an emphasis on 'science education as a process and a creative exercise rather than acquiring specifically defined knowledge and proficiencies' (MESC, 1999, p. 11).

Consequently the 1999 curriculum was analysed as a kind of 'quilt' phenomenon (Article I), featuring a synergy of different ideas and theories. It certainly endorsed the *role of subject matter* but also to a considerable extent *milieu of learners*. Although it focused mainly on *content and product* it was also partially *process-development* oriented. The position of *learners and learning* received more attention than *teachers and instruction* (figures 2a & 2b above). Consequently the curriculum developers and policy makers apparently adhered to an amalgam of ideologies, mainly social efficiency (cf. Schiro, 2008), learner centred and to a certain degree scholar academic. With regard to *scientific literacy* the goal was *promoting understanding of science and technology and its role in society and acquiring knowledge and skills to function in society*.

3.2 Transformation 1995 to 2007: A Synchronic Perspective

According to Ferdinand de Saussure (Harris 2001; Widdowson, 1996), studying human language from a synchronic perspective meant studying its status or cross-section at particular points of time, assuming that those who belong to the same community share the same language, but will use that language differently, and will have different communicative and communal uses for it (Widdowson, 1996). This thesis assumes that socio-cultural communities we call schools follow the same law and official curriculum, but will use the official guidelines differently. Schools may turn out to be 'particularistic' (cf. Elmore & McLaughlin, 1988) and vary regarding the use and interpretation of the intended curriculum (cf. Atkin & Black, 1996).

This thesis addresses the status or cross-section of the 1999 curriculum, outlining it as a *synchronic dimension* because the whole context of the intended and the implemented curriculum was taken into account, while the evolution from 1960 to 2010 was outlined as a *diachronic dimension* (See figure 5). Hence the 1999 curriculum was examined through a different lens than the three previous ones, considering the curriculum-in-action (taught and learnt) as well as the intended curriculum. The focus was on how the 1999 curriculum operated in various contexts from the events leading up to its adoption in the mid-1990s until its aftermath in the 2000s.

In order to study the 1999 curriculum from this point of view both researcher data and practitioner data were applied. First, the 1999 curriculum was considered in the *Five Teacher Study* (Appendix II) where its implementation was enquired into six years after its adoption. It was based on interviews and on-site observations with five distinctive science teachers about their professional ideas on learning and teaching science and use of ICT. The teachers were selected for the study because they had reputations as successful teachers in school science. Thus the sample was defined as purposive (McMillan, 2008). Articles IV and V were originally written in Icelandic and then translated to English. To make the text more manageable Icelandic pseudonyms of the participants were also changed over to English.

Second (Appendix III), the duration of the 1999 curriculum was studied from an *insider point of view*, within my own area of practice, meaning that the findings are to a considerable extent based on my work as a practitioner and a researcher from the time a new law came into effect in 1995 and until 2007 when the decision was made to change the official curriculum issued in 1999, decrease its central control through detailed objectives and increase an STS perspective (MESC, 2007a). Hence the sources of 'practitioner-researcher' data used in this thesis found place in my work as an educational advisor for Reykjavík Centre of Education (i. *Fræðslumiðstöð Reykjavíkur*), RCE, where model shools were developed among other projects.

Third (Appendix IV), my findings rest on my participation in the *Intentions and*

Reality Project (IR). The project comprised a large-scale study on science and technology in Iceland, and simultaneously an evaluation of the status of science education in each of the participating schools. The project was considered as interactively beneficial because each school received a report soon after the collection of data with supportive information and inputs about its status. I was a co-author of six IR-reports and a single author of one summary report about schools in the coastal east (Appendix IV). The IR project focused on the main features and impacts of the 1999 national science curriculum in force at the time of the study, the role of resources and learning materials, learning and teaching practices found in schools, support, school ethos and status of science in schools, skills, knowledge and professional attitudes; and nature of the gap between the intended science curriculum and the actual science curriculum.

Many intriguing themes emerged from studying the transformation of the 1999 curriculum synchronically. In order to answer the research questions six themes were considered most important. First a theme labelled *complexity of school cultures*; second *conflicting demands*; third, *preparation to teach science regarding CK, PCK and ICT*; fourth, the *'null curriculum' and abstention from teaching certain areas of science*; fifth, *science literacy and scientific literacy*; sixth, *nature of the gap/space between intentions and reality*.

3.2.1 Complexity of School Cultures

The first theme revealed in the findings was *complexity of school cultures* and diversity of practices. All the schools, the schools in the Five Teachers Study, the schools in the IR study, and the model schools had their own special ways of organising science learning and teaching. Some were compartmentalised, as an example the ECS model school (Appendix III, RCE-III), and likewise the school that Jacob belonged to in the Five Teacher Study. Fullan and Hargreaves (1996) described such compartmentalised school cultures as noncollaborative or 'balkanized' regarding the academic disciplines, meaning that each compartment was in a sense detached from the other compartments. The science teachers at ECS experienced themselves as isolated in their 'chamber' of science and they even felt opposition and misdoubt from other 'chambers' of the school: ' … what sort of impingement this was on behalf of the science teachers … it annoyed the old-line math and Icelandic teachers.' (RCE-IV). Jacob's school was an old-line lower-secondary school, entirely compartmentalised according do academic disciplines and he was alone as an expert in the science compartment.

Other schools reflected collaborative school cultures on the other hand, like the WES model school and Simon's school in the Five Teacher Study, stressing a thematic organisation of learning and integration of subjects. And there were examples of traditional practices where textbooks and workbooks were the predominant tools for learning and on the other hand there were examples of extremely progressive science activities, as an example in a small rural school with 21 pupils in first to tenth grade (age six to sixteen), where students took part in building a small hydro power station, a wind energy turbine, a greenhouse and a weather station (Appendix IV, IR-VI).

Diversity was also found among individual teachers and classes. If the five teachers (Appendix II) were placed on a continuum with respect to their praxis theories and curricular ideologies, featuring *behavourist views* on one end and *constructivist views* on the other, then Peter would be placed nearest to the behaviourist end: 'You might say that I teach in an old fashioned way … I make an effort of covering all the content students need to know or be acquainted with for the national examination', and he added that he did not believe much in student's self-controlled work, experiments or other hands-on tasks. Close to him would be Sage, then Jacob and Lin near the middle, but more though on the behaviourist side. Finally Simon would be near the constructivist end: '... if you start speculating with them, then somehow the flow changes. But if you are like you know it all ... they have to experience you see the process on their own premises, otherwise an understanding will not follow'. His school featured a progressive ideology basing projects and activities on the *Theory of multiple intelligences* (MI theory) (Appendix II).

The model schools were internally different in all respects, with regard to structure, learners' social background, size and organisation. The third model school, the one that deviated from the original plan, *Suburban Elementary School* (SES), adopted a new policy placing emphasis on environmental issues and outdoor learning instead of general science. In a new years greeting presented by the principal of SES in 2001 (RCE-VI) he reminded his staff and pupils that SES had become a model school in nature studies (i. *náttúrufræði*), ' … and [our school] aims at being an expert school in environmental and outdoor education'. His argument was that environmental issues were among the most challenging issues for mankind to deal with: 'SES places emphasis on environmental learning with the aim of promoting students' understanding and knowledge of their milieu and nature … [and will be able to] make decisions for the interest of our society and nature that all life bases its existence on'. This was also supposed to apply to the organisation of the school as a whole, its methods and procedures concerning exploitation of materials, energy and disposal of waste and garbage. Consequently the school culture of SES reflected an emphasis on issues that advocates of an STS theme in school science would propose, where social contexts and emotions towards nature were considered even more important than objective scientific knowledge and intellectual skills.

3.2.2 Conflicting Demands

The second theme labelled *conflicting demands* meant that pressure for content coverage conflicted with the demands on differentiation of instruction and constructivist views on learning. This was also confirmed in a recent study by Sigþórsson (2008). In *The Five Teachers Study* the teachers experienced a stress in these two conflicting areas, the demands made by the national curriculum and centralised evaluation, and an obligation to meet the needs of diverse groups of students. When Sage was asked about her view on teaching and learning she said that pupils learn best by carrying out experiments themselves but 'unfortunately the national examinations mean that they cannot do their experiments, especially because we went on strike ... we have to cover all the materials … that has to come first'. When asked if she listened for the ideas of pupils and asked them questions about their views and experiences she answered in the negative and said she did not feel comfortable with such teaching methods.

Jacob's position was an interesting example of trying to meet such demands rationally. He taught biology, physics and mathematics, and the national curriculum and national exams had considerable effect on his ideas about teaching and learning: ' ... the national curriculum is the main thread, at least in the science studies ... we also respect the studies and the exams ... they know they don't get away with any nonsense and not reading. My goals are reasonably clear and I test them and they know what they are'. Although Jacob may have seemed enchanted with accountability, clear objectives and a content-product oriented curriculum, he confirmed that he respected ideas of variability among pupils and taking into account their prior ideas and experiences. Our on-site observation witnessed that he was good at promoting student conversations with challenging topics, even though they reached beyond the predetermined content to be learn at that time. When asked about discourse beyond the predetermined curriculum he replied that he considered such lessons valuable when 'everybody is interested because it comes from them' (Appendix II, Article IV).

Among controversial issues at the 1997 meeting (Appendix III, RCE-I) was an alleged weak external and internal control of science education in compulsory schools (Grades 1-10). Most of the representatives that attended the meeting agreed that school science needed more control. An attention was devoted to centralized assessment of achievement and it was pointed out that centralized examinations (i. *samræmd próf*) had not been operative since 1983. Most attendants agreed that such tests were likely to promote science learning, but special precaution was needed regarding the selection of contents for the tests, their development and application. They also agreed that systematic evaluation of science learning and teaching in schools was needed (Appendix III, RCE-I).

Similar findings were revealed in some of the interviews in the IR project (Appendix IV) and the Five Teacher Study (Appendix II). A teacher in one of the rural east schools in the IR project (Appendix IV, IR-II) argued that the centralized tests embodied certain benefits, and helped maintaining the quality of learning and teaching science, but at the same time he was sceptical whether or not they were the best means to do so taking their nature into account as it was at that time: 'If we would manage to make the tests more authentic and thematic and relate their contents more to students' own milieu and interests, even extend their function by allowing students themselves to participate with self-assessment and peer-assessment, then we might be on the right track' (Appendix IV, IR-II).

3.2.3 Preparation to Teach Science Regarding CK, PCK and ICT

The third theme reflects concerns about teachers' weak preparation to teach science with respect to *content knowledge* (*CK*), *pedagogical content knowledge* (*PCK*) and the application of *information and communication technology* (*ICT*). Such concerns were repeatedly perceived when analysing the data. In the meeting held at RCE in December 1997 (RCE-I) teacher education was a central issue, both continuing professional development (CPD) and initial teacher training (ITT). A chairman of a committee preparing the official science curriculum for the Ministry of Education (RCE-I) argued that the relationship between knowledge of and about the contents of science (CK) and subject-specific competencies to teach science (PCK) seemed to be in need of serious consolidation. Similar implications were found in the 1997 survey (Þórólfsson & Birgisdóttir, 1998; Appendix III, RCE-II), in the final report of ECS (RCE-III), and interviews with model school teachers. According to an interview with a WES teacher the teachers from that school received some training in connecting CK and PCK: 'It was an important benefit that all our teachers attended the course at the University, especially in relation to physics' (RCE-IV), but in the long run it appeared that teachers at WES would have needed additional support in form of CPD. The ideas and competencies received through the University course seemed to wane as time passed ' … it became more like social studies and some Icelandic and such subjects … so there wasn't much natural science left'. The interviewees at WES also expressed their concerns that some teachers spent more time at dealing with settings instead of addressing the science content as such: ' … then it ends in a Power Point show where you are more occupied with the settings, cut and paste and finding some fancy fonts'.

The Five Teacher Study indicated a rather weak subject-specific use of ICT even though the participants had a reputation generally for being effective science teachers. Science teaching practices reflected to a minimal extent the aims in the national curriculum on the nature and function of science and the skills and methods of science. Instead it seemed that each had his or her own 'theory of teaching' which reflected the extent to which he or she used or chose to use ICT in school science classes. The emphasis seemed more on content than process, using ICT as a transmission-of-knowledge tool functioning as a support or an addition to other tools such as textbooks, rather than using it as means to transform learning and teaching, for example for promoting enquiry or using spreadsheets for data logging and graphing. The IR project indicated that the use of ICT in science classrooms seemed close to 'square one'. Assignments that were not done through handwritten class books were perhaps done with Word or PowerPoint, but use of graphs, charts, simulations or the Internet at large appeared to be negligible.

In the 1997 survey (Appendix III, RCE-II) answers from both middle grade teachers and lower-secondary teachers indicated that the idea of school science as a study of facts and rules to be memorized and practiced seemed to be strong. Some participants even argued that better textbooks were needed (Appendix III, RCE-II). In WES an inclination was found among many teachers to 'take it in small sections and then have a test immediately afterwards ... just as it used to be' (RCE-IV). Thus learning through enquiry seemed rare and beliefs that students learn best by being active themselves in dealing with problems and discovering structures were not much evident, in spite of such emphases in the official curriculum. The same was also found in the IR study that investigative work in school science offering open-ended solutions, seemed not very popular in the schools studied (IR-I). Instead, the central role of teachers seemed to be transmitting knowledge with textbooks as a basic medium, rather than addressing misconceptions and learning problems among students, and practicing 'ways of representing and formulating the subject that make it comprehensible to others' (Shulman, 1986, p. 9).

Textbooks for Icelandic compulsory schools are traditionally developed by the National Centre for Educational Materials, NCEM, (i. *Námsgagnastofnun*) and research affirms that Icelandic teachers seem to rely greatly on written learning resources and assignments related to written texts (Macdonald, 1993; Sigurgeirsson, 1992; Sigþórsson, 2008); the textbook for each subject and grade, for example 'science for 5th grade', appears as a central instrument in the minds of teachers. But actually there is no such thing as 'science for 5th grade' or any other materials earmarked by the NCEM for certain grades, though some learning materials have been written with respect to certain stages of the compulsory school. Textbook alternatives are fuzzy (Appendix III, RCE-II), non-teacher-proof, and therefore it is hard for teachers who are weak regarding CK and PCK (cf. Shulman, 1986; 1987) to find suitable materials.

3.2.4 'Null curriculum' - Abstention from Teaching Certain Science Areas

The fourth theme includes a problem related to curriculum theory. Elliot W. Eisner (1985) termed it as the *'null curriculum'*, referring to content that is traditionally excluded from school curricula. Actually, Eisner's point was that curriculum developers tend to select content merely out of habit and because it has been part of an academic tradition, and neglect areas that prove to be useful to students. In this thesis the idea of an *abstention from teaching certain areas of science,* may sound like a contradiction to this view. An abstention from teaching physics is bound to sound like a paradox with respect to Eisner's ideas; but the fact is that providing learning contexts for students to satisfy their curiosity about the physical world whether from a subatomic view or a cosmic view or any view in between, is clearly as relevant as any other action in education. As Eisner argued, schools have consequences not only by virtue of what they do teach, but also by virture of what they neglect to teach. Arguing about the beauty and conservation of natural phenomena, drawing pictures of birds and animals, reading poems about them, and reciting their names and characteristics are hardly more important learning activities than exploring and discussing heat, substances, forces, motion, sound, viscosity or buoyancy of fluids.

The findings indicated that information on what kind of science took place in Icelandic classrooms proved to be fuzzy. The survey conducted in 1997 (Þórólfsson & Birgisdóttir; Appendix III, RCE-I) confirmed that multiple aims, contents and learning materials were in use, and there were examples of schools or in some cases particular teachers that ignored certain elements of school science, in particular topics related to physics or chemisty in grades below 8th grade (13 years of age). This was also confirmed through interviews with ECS and WES teachers: 'The emphasis was especially on raising the prestige of physics, chemistry and earth science … in recent years teachers have pleaded not knowing and admitted "fear" of tackling instruction in these areas of school science' (Appendix III, RCE-V). And as the project continued it turned out that many teachers tended or tried to abstain from tasks related to these areas, not least hands-on assignments.

Consequently internal control proved to be just as weak as external control. An interview with Sage in the *Five Teacher Study* also confirmed such weaknesses in internal control where she taught: ' … but there is one problem in our school, which is that teachers don't teach physics, that is class teachers in general'. Sage had even made practical and user friendly kits for first to fifth grade teachers to help them with hands-on teaching about magnets, forces and electrical energy, but her ideas did not seem to work as expected, a minority of class teachers seemed to have courage or confidence enough to use them.

Related to this was an issue discussed at the 1997 meeting, i.e. the interesting fact that in IEA's international survey in 1995 (TIMSS) Icelandic students scored well above average when asked to determine the age of a tree by counting annual growth rings – knowledge which can easily be learnt from a book or from a teacher keen on growing trees – but they knew much less than the average student about physical phenomena, such as atoms, molecules and cells, or large-scale contexts such as the importance of light for an ecosystem or the existence or function of gases in the atmosphere (confirmed in Beaton et al., 1996).

3.2.5 Science Literacy and Scientific Literacy

The fifth theme comprehends the most debated issue in school science in recent decades. It concerns finding a reasonable middle course between a focus on science education for an enlightened citizenry and science education for an intellectual elite; ergo it purports the question in what manner the findings reflect ideas of *scientific literacy* and *science literacy*. As indicated above (Bennett, 2003) *scientific literacy* concerns the ability to understand and discuss scientific matters, but *science literacy* concerns talking, writing and reading abilities in science. Either which we prefer to focus on, talking about literacy related to science will be pointless if specific ideas, concepts and language of science are left out.

In analysing the official curricula from 1960 to 2010 (Article I) the focus was largely on the conception of literacy. Though the phrases themselves 'scientific literacy' or 'science literacy' were not found in the official curriculum guides, the guides did address competences that can at least be regarded as a push towards literacy in science. As Article I indicated the knowledge of science component was clearly emphasised in the 1960, 1976 and the 1999 curricula, stressing knowledge of concepts, and acquisition of knowledge and skills to function in society. The knowledge about science component, stressing scientific enquiry and explanations, was accounted for in the 1989 and 1999 curricula, and also the contexts component comprising health issues, climate change, and environmental issues.

Regarding the synchronic perspective around the 1999 curriculum, it should be kept in mind that it was in stark contrast with previous national curricula due to the detailed objectives in life science, physical science and earth science assigned to all grades from first grade to tenth grade and at the same time views on science education as a process and a creative exercise with an emphasis on understanding fundamental aims related to sustainable development and critical thinking about environmental issues. This means that the 1999 curriculum actually promoted both scientific literacy and science literacy, although the two terms were not found in the curriculum text.

Among concerns in the IR project was that both students and their teachers seemed in need of a certain level of literacy in order to access science in general and the textbooks on science. Discussing a topic requires some fundamental knowledge and specific vocabulary related to that topic. Furthermore it calls for an understanding and the ability to link together 'ideas from a range of experiences of real phenomena, problems and events' (Harlen, 1996), and last but not least positive attitude towards the topic. If there is a call for enhanced class discussions and hands-on activities, the results inevitably depend on the extent to which teachers themselves feel comfortable with the topic under study. Consequently, literacy in science requires knowledge of science, knowledge about science, identifying scientific matters in various contexts (personal, social and global) and attitudes towards science (interest, support and responsibility) (OECD, 2006).

As indicated in sections 3.2.1 to 3.2.4 school cultures featured multiplex images regarding literacy in science; the same applied to qualities and dispositions of teachers. All facets of literacy in science as presented according to four ideologies in Article I were found in schools at the turn of the last century: Knowing and understanding scientific concepts, methods and laws according to scholar academic ideas, acquiring knowledge and skills to function in society according to the social efficiency ideology, promoting learners' growth and understanding of science according to the learner-centred ideology and promoting critical thinking and discourse about science and its role in the social context to which the student belongs and its role in his or her life according to the social reconstructionist ideology.

Some teachers proved to be hard-working and enthusiastic but lacked content knowledge (CK). Others were fairly well set regarding content knowledge but admitted that their pedagogical knowledge (PK) and pedagogical content knowledge (PCK) was excessively weak. When Sage of the Five Teacher Study was asked about a CPD course in physics she had attended she answered that she had no need for more learning about the contents of physics, what she needed was how to do things in the classroom, how to conduct experiments and hands-on activities and ' … as I said, I'm not good at asking questions and keeping conversations going'.

3.2.6 Nature of the Gap between Intentions and Reality

The sixth theme concerns the space between the intended curriculum and the curriculum-in-action, i.e. the main research question of the IR project: *What is the nature of the gap between the intended curriculum and the actual curriculum in school science and technology – the intentions and the reality?* In IR the synchronic dimension was actually referred to as the 'space' or the 'gap' in which the actual curriculum was constructed with respect to the intended curriculum. It was conceived as the space where the intended curriculum meets the curriculum in action (implemented curriculum). As already affirmed the IR study indicates that the users of the 1999 curriculum, typically teachers, were bound to perceive it and interpret its contents according to their own preconditions, education, disposition and facilities. The findings affirmed this clearly. The three content areas of the curriculum, physics, biology and earth science, were unequally covered by teachers, in some cases poorly covered, for example physical science. Furthermore the actual process of teaching and learning proved to differ largely from one class to another.

Despite emphasis on practical work in the 1999 national curriculum, such work was identified as a key element missing from science classrooms. In other words, the IR study affirmed that there was a gap between the intentions of the national curriculum of 1999 and the capacity of teachers to implement them. But the IR final report (IR-I, p. 5) argued that the gap might in fact work both ways, i.e. we really needed to understand what sort of science curriculum had *de facto* been in place. The science content shapes teaching and learning processes; but pedagogy and learning processes, being focused on, also shape the content learnt. And it should not be overlooked that science was being taught in Icelandic schools according to predefined timetables where textbooks were of paramount importance and had much to say about the way science was and could be taught. Frequently the disciplines were separated in the timetables, allocating special time to each discipline: physics, chemistry and biology, while earth science was frequently under the umbrella of geography. Finally it was argued that students and even sometimes their teachers needed a certain level of literacy in order to access science in general and textbook science. Discussing a topic requires some fundamental knowledge and understanding related to the topic, and last but not least positive attitudes towards the topic. Class discussions will depend on the extent to which teachers themselves feel comfortable with the topic under study.

CHAPTER 4

DISCUSSION AND IMPLICATIONS

Figure 4 gives an idea of the nature and structure of this thesis. It focused on the transformation of the official science curriculum for compulsory schools in Iceland over a period of fifty years. The transformation was examined from a *diachronic perspective*, meaning that it was explored as it evolved over time, and also from a *synchronic perspective*, meaning that its operation at different levels was examined at a certain point of time around the turn of the last century with a particular interest in the space between policy and practice, that is, curriculum as intended and curriculum as enacted in various contexts.

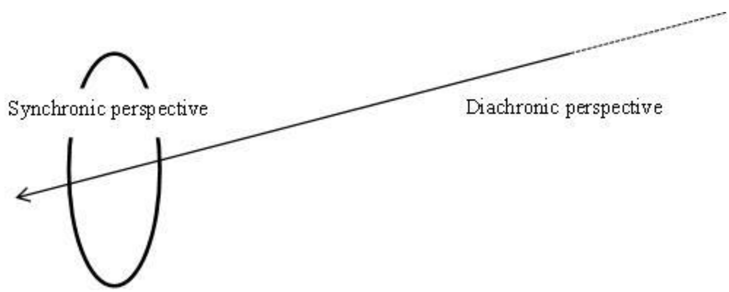

Figure 4. Nature and structure of the thesis. This research was based two conceptions borrowed from linguistic research, the *diachronic perspective*, and the *synchronic perspective*. The diachronic dimension reflects how the curriculum has evolved over time. The synchronic dimension reflects the complexity of the space between policy and practice.

The findings of this research indicate that the whole curriculum is 'alive' in the sense that its constant evolution resembles transformations of organisms found in a biosphere. It alters its general character and mode of life from one time to another and it proves to be extremely labyrinthine when studied synchronically.

4.1 Transformation 1960 to 2010: A Diachronic Perspective

The diachronic perspective (Appendix I) indicates how the curriculum has evolved over a period of fifty years, 1960 to 2010. The official curriculum guides for school science were analysed as delineated in Articles I and III.

4.1.1 Churning Curriculum Designs

The transformation of the science curriculum appeared to come about as interplay between two kinds of curriculum designs. In Articles II and III these were termed as 'Darwinian design' on the one hand and a 'deliberate design' on the other hand (cf. Papert, 1997). A 'Darwinian design' refers to Darwin's theory of evolution, where complex systems evolve from more simplistic predecessors and favourable modifications, mutations as in genetics, are preserved because they prove advantageous. A 'deliberate design' refers to human change efforts, either small-scale or systemic like the 'new science' curriculum reform in the 1960s and 1970s. Although such change efforts may appear as temporary policy churns and seem to fade as time passes, favourable modifications tend to be preserved and passed on to future curricula. Teachers and administrators in schools modify new ideas and methods to fit their conditions, the nature of their (traditional) work setting and the ways in which they define their tasks of seeing that students learn the standard curriculum (Tyack & Cuban, 1995).

Moreover the findings of this research support the point made by Donnelly and Jenkins (2001) that incessant transformation of the school science curriculum is so firmly chiselled into the system that it becomes an 'orthodoxy', whether we perceive it and talk about it as reform, natural evolvement, progress, developmental process, incremental change, or simply change. Consequently science education proves to be extremely dynamic in nature, and the science curriculum appears as becoming what Stinner and Williams portrayed as 'a weed patch of trivia and esoterica rather than a carefully-tended garden of worthwhile knowledge' (2003, p. 1027). Instead of embodying a pattern where everything has the appearance of being rational, contextual, and easily measured, the system appears chaotic to a certain degree, and increasingly disordered, like Hawking (1998) pointed out with his conception of the thermodynamic arrow of time, a measure of an increasing disorder of the world.

According to the theory of evolution in life science, complex systems evolve from more simplistic predecessors. The school science curriculum seemed to evolve in a similar manner. Examining the transformation of rationale, aims, contents, and context gave an impression of a dynamic system gradually becoming saturated with 'trivia and esoterica', where it proved hard to decide what was sensible to keep and what to remove. As time passes the curriculum comes into view like a collection of loosely attached ideas or frameworks based on different philosophies about what should be the purpose of school science, what should count as legitimate knowledge, and hence what should be taught and learned, how and why.

4.1.2 A Myriad of Ideas and Topics

Actually, this noteworthy tableau of the transformation of the science curriculum calls for the use of a third chronology conception, *anachrony*, because some important curricular phenomena appeared not to follow a chronological order completely; sometimes the ideas or conceptual frameworks based upon seemed chronologically out of place. For example the contents and methods of the 1976 curriculum were still detected in practice in the 2000s and even also contents and methods descended from the 1960 curriculum.

Emmanuel Lévinas (Hutchens, 2004) used this concept of anachrony, to account for the pasts, presents and futures of all the others, whether dead, absent or unborn, in which the self could not share. Thus the manifestation of anachrony is worth noticing from another point of view than the above, that is accepting the fact that phenomena do emerge from the data that prove hard to explain. Although the conceptual framework of the 1960 curriculum for example proved to be content-product rather than process-development directed and was analysed as promoting the position of teachers, instruction and subject matter rather than learners and their milieu, there were intriguing proposals that gave a glimpse of 'constructivism', a concept totally unknown in educational discourse at that time. The proposals felt surreal because they literally reflected present constructivist discourse, like 'relating new knowledge to prior experiences, stressing hands-on learning and discussion' and: '[In Local studies] children are brought into a world ... not in such a manner that they feel they are being instructed about it, but rather as if life itself unfolds for them through their own activities and observations.' (ME, 1960, p. 28). As pointed out in section 2.2.4 constructivist pedagogy *per se* is actually not a new conception in education although the word may have emerged in educational discourse in the 1970s; it draws on the work of Lev Vygotsky, John Dewey, and many other thinkers of the early 20th century progressive era (Popkewitz, 1998) and in fact much further back (Glasersfeld, 1991). The 1999 science curriculum was portrayed as a 'patterned quilt', an amalgam of ideologies, because it featured a mixture of all the ideologies that Michael Schiro (2008) presented: Social efficiency ideology with detailed aims and objectives, learner-centred views reflecting exercises according to needs and interests of learners, and also to some degree social reconstructionist ideology and scholar academic ideology.

Actually the ideologies reflected the big picture, but as Stinner and Williams (2003) argued, the devil always seems to appear in the details, the incremental myriad of ideas and topics accumulating in the science curriculum, subjects and disciplines (botany, physiology, physics, zoology, nature study, biology, physics, earth science, real science …), conceptions such as STS (Science-technology-society), STEM (Science-technology-engineering-mathematics), sustainable development, science for all, information and communication technology, life adjustment science, academic science, science literacy, scientific literacy and many more.

4.1.3 History of Science, Nature of Science and Literacy in Science

While arguing that the school science curriculum was becoming a crowded place, Arthur Stinner and Harvey Williams (2003) surprisingly proposed new conceptions to be added to the curriculum: 'Our proposal is that the History and Philosophy of Science (HPS) become a central theme in the science curriculum and that HPS and science content knowledge are integrated into a contextual matrix of science stories and large context problems' (p. 1027). The argument sounds convincing: introducing HPS into school science should make learning contextual and relevant to students, and make science comprehensible, motivating and meaningful. The historical context should help students understand the present status and role of science and technology and hence advance what we call literacy in science for all.

There is a general agreement among educators and specialists in science that literacy in science is essential for all citizens. Although the phrase 'scientific literacy' was not found in any of the four curriculum texts analysed in this study, they did address competences of diverse kinds that can at least be regarded as a push towards what the literature regards as either *scientific literacy*, that is the ability to understand and discuss scientific matters, or *science literacy*, talking, writing and reading abilities in sciences. The four components introduced in PISA 2006 as a framework of competences in science (OECD, 2006), were knowledge *of science*, knowledge *about science*, *identifying scientific matters* in various contexts (personal, social and global), and *attitudes towards science* (interest, support and responsibility).

The analysis of the four national curricula, 1960, 1976, 1989 and 1999, demonstrated that the 'knowledge of' focus and consequently knowledge transmission gradually seemed to decrease to some extent from the 1960 curriculum, where the position of the teacher was assessed as strong to weak in the 1999 curriculum. But still it should be noticed that the position of subject matter generally kept its strong status, except in the 1989 curriculum. Although the position of learning and milieu had increased from being very weak in 1960 and 1976 to being strong in the 1989 and 1999 curricula, the content-product model appeared stronger than the process-development model in all the curricula, except the 1989 curriculum (Article I). Thus the idea of *science literacy* focusing on talking, writing and reading abilities in the sciences seemed generally more visible in the four official curriculum texts, whether the old nature studies were involved (zoology, botany, physiology …) or biology, physics and earth science as in the 1999 curriculum. The ability to understand and discuss scientific matters, *scientific literacy*, seemed less visible on the other hand, that is knowledge about science, identifying scientific matters in personal, social and global contexts, and attitudes towards science.

The idea of an 'emerging information society' connotes that producing, manipulating, and interpreting information, including scientific information, has become a critical economic and cultural activity. The introductory message of Article I was:

> Countries and cultures rely increasingly on proficiency and information related to science and technology; science educators agree that all citizens need to be empowered to apply such information and skills in various contexts. Consequently science education reforms have focused progressively on promoting what has been called literacy in general science for all learners. In spite of such endeavors, history has taught us that the 'grammar and syntax' of the scientific disciplines do prevail, where school science is perceived 'as a basic preparation for a science degree – in short a route into science. Such curricula focus on the foundational knowledge of the three sciences – biology, chemistry and physics' (Osborne & Dillon, 2008, p. 7). The ideas of literacy in science may take on different manifestations depending on the curriculum ideology built upon. (Article I, p. 2642)

Our culture relies increasingly on information and proficiency related to science and technology in a broad sense; it needs special expertise in many areas and it also needs general understanding and knowledge about scientific matters and competencies to apply that knowledge. Hence we must bear in mind the needs of two main learner groups that Peter Fensham (1985; 1986/1987; 1988; 2004) labelled as future scholars and scientists on the one hand (about 20% of an age group), and on the other hand those who will not necessarily continue with formal education in science, but future citizenry needing to become reasonably literate regarding science and technology and its role in our culture (about 80%). *Ergo*, my conclusion is that future curriculum developments must focus on what Paul DeHart Hurd conceived as 'the gap between academic science and science for the citizen' (1998, p. 414), *nota bene*, by acknowledging these two perspectives evenly and striving to interweave them in an effective manner with respect to fundamental aims of compulsory schooling. I believe that context in general science where we integrate our accumulated understanding of natural phenomena in a manner that Stinner and Williams presented under the rubric of HPS (see above) is fundamental, including what has been portrayed as *nature of science* (NOS), namely a perspective on science as it has developed through history, how it has affected social and economic factors of human society and what roles scientists have played in this process (Enger & Yager, 2001). This means that we need to define and put into coherent context important concepts from the multitudinous areas of science at large, such as biology, chemistry, earth science, physics, ecology, genetics, or limnology. The most sensible model must be to integrate such areas and examine and discuss how all this works in harmony.

4.2 Transformation 1995 to 2007: A Synchronic Perspective

The synchronic perspective (Appendices II, III and IV) denotes how the curriculum operates at a particular point of time. The 1999 curriculum was examined transversely, considering the curriculum-in-action (taught and learnt) as well as the intended curriculum. Hence the focus was on events in the mid-1990s leading up to its adoption and until its aftermath in the 2000s.

4.2.1 Miscellaneous School Cultures and Central Control

As identified above, the whole curriculum was perceived as being 'alive' and analogous with transformations of organisms that we find in the biosphere, chronically altering its character and mode of life and being extremely maze-like when studied synchronically. The complexity of school cultures appears as though there are many 'curricular dialects' in operation simultaneously. At the same time you might find a school that reflects ideas of the 1960 curriculum, mainly teaching life science as botany, zoology and physiology, another school that processes science in a manner emphasized in the 1976 curriculum, a sophisticated academic discipline, a third school organizing its schedule around the detailed objectives as presented in the national curriculum, a fourth school integrating nature studies and social studies and finally a school being extremely progressive like the small rural school where students took part in building real energy conversion structures, a greenhouse and a weather station (Section 3.2.1).

The findings also affirm that if we placed teachers and administrators on a continuum with an emphasis on a *teacher-as-transmitter-of-knowledge view* on one end and a *learner-as-constructor-of-knowledge view* on the other, then the subjects of this research would scatter over the whole axis. You could even find extreme examples like Peter on the one end who said he 'taught in an old-fashioned way' and made an effort of covering all the content that students needed to know for the national examination, and on the other end Simon who emphasized speculations 'with them' and chose not to present himself as a sage who knew everything.

This image of the science curriculum as operated in compulsory schools at the end of the last century must be considered from two intertwined perspectives. The first perspective concerns internal and external control. According to research in mid-1990s, for example findings regarding Iceland in the TIMSS study (Beaton et al., 1996), both internal and external control of the school science curriculum were considered weak at that time. There were even examples of teachers who said they had the power to decide everything by themselves, what to teach and how to (Articles IV & V). This was also confirmed at the meeting in 1997 (RCE-I). The second perspective concerned the rapid changes that the educational landscape undertook at that time. Despite decentralization of the management of education resulting in enhanced liberty handed over to municipalities for policy making and curriculum development, there were other changes that unmistakably had features of central control (cf. Sigþórsson, 2008). The new law in 1995 promoted more central inspection than had been before, and the 1999 curriculum with detailed aims and objectives and the return of centralized national examinations signified less internal professional autonomy and more external management requiring uniformity regarding goals and contents.

4.2.2 Constraint or Feasible Intervention?

As indicated above, this development was bound to raise questions about the professional independence of teachers and schools in planning their school science curricula according to their contexts and needs, bearing in mind that school structures and cultures studied here proved to vary immensely. Nevertheless this was a time where many influential scholars (cf. Committee on Educational Policy, 1994) adhered to the idea of a clearly formulated central curriculum for all Icelandic compulsory schools and a national examination, synchronous to local control of schooling.

Being in favour or in opposition to such ideas is probably more complicated than appears to be at first glance. It concerns our answers to fundamental questions like: Why is science part of the school curriculum? What should be learnt and taught in science, how and why? The answers to such questions concern economic, practical, social, cultural and political issues. The four arguments that Osborne (2000) identified as important in this respect were the *utilitarian*, the *economic*, the *cultural*, and the *democratic* argument. It can hardly be denied that learners benefit in a practical sense from learning science, or that our society relies on scientifically and technologically educated citizens to function. Nor can it be denied that science is among the most remarkable achievements and foundations of our culture and must be treated as such. Finally, it is hard to deny that a democratic society requires the participation and involvement of all its citizens because most controversial issues facing our society are related to science and technology in one way or the other.

Most professionals and non-professionals probably agree with Osborne's arguments, so the first question above is possibly not a problem. But the second question, about what should be learnt and taught in science, how and why, may turn out to be harder. As the Five Teacher Study confirmed all the participants had their own specific views on what was most important to teach and learn, by what methods and educational experiences, and how learning should be assessed. Trying to change such views would probably not be an easy task. It is well known from the research literature (Elmore, 2008; Fullan, 2001; Tyack & Cuban, 1995) that teachers tend to resist change suggested or mandated by others. A clearly formulated central science curriculum for compulsory schools and a national examination, as was suggested and implemented at the turn of the last century, must obviously have entailed difficult circumstances because of the diverse ideas and practices that had been customary in schools. Asking teachers and students of the small rural school (See sections 3.2.1 & 4.2.1) to stop being engaged in building energy conversion structures and start learning scientific concepts, law and processes expected to be assessed on a central examination could evoke hard feelings:

> Experienced teachers who have been successful, and consequently have developed great confidence in their teaching skill, are usually asked as part of reform to try new methods or teach new content that makes them feel again the novice's uncertainties and clumsiness. In addition to the bad feelings this may cause, teachers worry about how it may harm students. (Walker & Soltis, 2009, p. 89-90).

Consequently we must consider thoroughly all possible consequences of an intended curriculum change, bearing in mind that the actual curriculum is 'alive' and wondering whether it will work as a constraint or a feasible intervention for all stakeholders. Reforms increase demands on teacher's knowledge and skills, so we must also consider to what extent reformers should involve teachers themselves in change processes.

4.2.3 Teachers' Part in Delivering School Science

In the mid-1990s, i.e. the time leading up to the adoption of the 1999 curriculum, there was an intensive debate about knowledge and skills of teachers and their preparation to teach science according to the new curriculum that was being introduced, first through a set of goals in 1997 (MESC, 1997). In the 1997 meeting there was a consensus that both continuing professional development (CPD) and initial teacher training (ITT) needed reinforcement, and it applied to both content knowledge (CK) regarding school science and pedagogical content knowledge (PCK). The 1997 survey (Þórólfsson & Birgisdóttir, 1998; Appendix III, RCE II) indicated that a transmission-of-knowledge model seemed to prevail and Icelandic teachers seemed to rely greatly on written learning resources and assignments based on written texts.

Another no less worrying finding, already in 1997, was that there were schools that did not teach certain parts of school science, teachers who said they avoided taking into account certain areas of science and even some teachers that confirmed that such areas were not taught due to a lack of interest (cf. Þórólfsson & Birgisdóttir, 1998). Interviews with teachers from WES model school with grades 1 to 7, taken in 2005, confirmed that physics and chemistry had not been on the school's agenda for several years before the school applied to become a model school in science. Furthermore, the findings indicate that learning through enquiry seemed rare and beliefs that students learned best by being active themselves in dealing with problems and discovering structures were not much evident.

This image of ignorance that the findings gave of the enacted school science curriculum at the end of the last century gives rise to serious debate about what Eisner (1985) identified as the 'null curriculum'. According to Eisner ignorance could not be interpreted as a 'neutral void', because ignoring certain contents or ideas would have effects on options and alternatives, and the perspectives from which students would be able to view situations and problems (Eisner, 1985). Among manifestations of the 'null curriculum' according to Eisner was the fact that educators, such as teachers, have different ideas about the importance of various parts of the official curriculum. Given that they do not find enough time to 'cover' everything, they evidently choose what they consider more important or what they feel more comfortable with. Teachers may even choose topics simply because they find them more enjoyable or believe that the students will find them interesting (Eisner, 1985).

Another aspect of this dilemma of the 'null curriculum', that might be termed as an 'inheritance effect', is the fact that teachers inevitably ignore contents and ideas that have been ignored through their own school attendance, i.e. contents and ideas that they know little or nothing about; and do not forget that school attendance includes their initial teacher training (ITT) too. Thereby ignorance does not only have effects on options and alternatives *per se*, and the perspectives from which students are able to view situations and problems. It is also 'inherited' and has effects on the education of others too.

4.2.4 The Intervening Space Between Intentions and Reality

A chain can never be stronger than its weakest link. Van den Akker (2003) identified ten major components or links comprising a curriculum for education. They were *rationale*, *aims & objectives*, *content* and *time*, that would be most evident at the macro and meso levels, that is the intended curriculum, and to some extent the implemented curriculum. Then there were *learning activities*, *teacher roles*, *materials & resources*, *grouping* and *space*, most evident at the micro level, that is the curriculum as enacted in classrooms. The tenth link, probably the most important one along with the rationale, was *assessment* requiring 'attention at all levels and representations since alignment between assessment and the rest of the curriculum appears to be critical for successful curriculum change' (van den Akker, 2010). This classification is helpful when discussing the space or the alleged gap between the intended science curriculum, and the curriculum in action. The classification may nevertheless be inconclusive in come contexts. Allocation of time for subjects is for example found in official written curricula as in schools, e.g. in the Icelandic national curriculum for compulsory education (i. *Aðalnámskrá grunnskóla*). Actually all of the ten components are more or less addressed in the implemented curriculum.

If the synchronic dimension is conceived of as the 'space' in which the real-life curriculum is constructed, it is the crucial point or 'commissure' where the intended curriculum is perceived and interpreted by its users, and decisions are made about the process of learning, teaching and assessment. The Five Teacher Study and the practitioner-researcher findings confirmed that there was a definite gap between the intentions of the national curriculum of 1999 and the capacity of teachers and administrators to implement them. This meant that there were either weak links or missing links regarding the operation of the curriculum as a whole. According to the data, important elements of the 1999 national curriculum, such as hands-on activities, use of ICT, and practical work proved to be missing from many science classrooms, and many teachers seemed excessively contingent on using written texts as main learning materials. Finally, there were haunting questions about the relationship between scientific literacy and critical discussion about scientific or technological issues. Discussing such issues requires fundamental knowledge and understanding, and competences that would fall under the rubrics of CK and PCK.

4.3 Implications

Science is probably the most auspicious field of knowledge for providing humans with an understanding of their physical world, and hence fullfill our natural curiosity about our existence: We do want to know why we are here, and where we came from, and we want to be able to construe our world (Hawking, 1998). Nevertheless, economic, social and utilitarian arguments for science education always seem to have been stronger than personal or humanistic arguments. In the nineteenth century it was argued that knowledge of science was important for utilitarian purposes and for the development of mental powers (DeBoer, 1991). About 100 years ago studying science was argued for as a preparation for effective living in an increasingly industrialized world. Since the new science wave in the 1960s we have encountered conflicting arguments for learning science, firstly as a sophisticated academic discipline, secondly as means to enhance scientific literacy, STS and STEM, and thirdly as means to promote education for sustainable development (ESD).

Implications of multiple curriculum practices from all times were found in this study. As identified earlier in this thesis, schools in the study turned out to be 'particularistic', each choosing its own special way of organizing science learning and teaching. There were progressive schools like the small rural school where pupils participated in energy conversion technology, there were schools that emphasized outdoor-learning and environmental issues like the SES model school, and there were several schools that counted mainly on written materials and practiced teaching for factual knowledge, even rote learning. Finally there were schools that deliberately pursued a 'null curriculum', regarding certain areas of science as less important than others. According to DeBoer (1991), a diversity of curriculum practices as identified above can be summarized as three dominant approaches in the development of school science curricula:

> Teaching the science disciplines as structured bodies of knowledge to be learned as logically organized subject matter
>
> Teaching science as a set of investigative processes
>
> Teaching science as a human activity closely interconnected with its technological applications and with the rest of society
>
> (DeBoer, 1991, p. 219)

None of these approaches and ideologies supporting them lack advocates. And after all, we still can not deny Herbert Spencer's conviction from 1859 that science ought to form a major part of the school curriculum, taking all views into consideration. Knowledge and skills in science and technology empower us to think, investigate, identify and react responsibly to critical issues and problems in our society, whether the contexts are personal, social or global, and whether the advocates emphasise social relevance, disciplinary study, process-development or content-product. Hence ideas of literacy in science, whether termed as scientific literacy from a socio-cultural standpoint or science literacy from a theoretical standpoint (cf. Roberts, 2007), seem evenly valid.

It is a matter of opinion if there is any one best science curriculum for all, with one best set of answers to the following questions (cf. van den Akker, 2010):

Why are our school children learning science?
Toward which goals should they learn?
What are they supposed to learn in science?
How are they supposed to learn?
What should be the role of the teacher in facilitating science learning?
What kinds of materials and recources fit best?
With whom should they be learning science?
Where should they learn, what kind of milieu fits best?
When should our children be learning science?
How should we assess science learning?

However, there are certain criteria that we need to agree upon. At its essence, science is not a typical book study based on recitation of some vocabulary. It is a curriculum field that involves contact with physical phenomena, both sentient and insentient, and investigation of such phenomena as structured and in context, not as disordered 'trivia og esoterica': ' … unless detail is placed into a structured pattern, it is rapidly forgotten' (Bruner, 1966, p. 2). Bruner and numerous other writers through the history of science, such as Kant, Dewey, Montessori, and Piaget have pointed out that relating new ideas to something that a student already knows and linking them to form networks of meaningful ideas is a powerful strategy in science education. Flow of energy is an example of a central conception hard to grasp unless it is placed into a structured pattern related to familiar areas of science, whether in life science (e.g. various manifestations of photosynthesis), in physical science (e.g. heat and the idea of entropy), in earth science (e.g. geothermal heat) or in cosmology (e.g. 'downhill' flow of energy in the universe). Furthermore, the nature of science as a learning field requires that students are provided with time and opportunities to investigate and discuss topics they are engaged in.

This certainly means that schools need human resources with qualifications to organize and facilitate structured science learning with respect to its wide-ranging contents and specific nature as a school subject. Moreover, the system must ensure that each school has some internal control regarding content knowledge, pedagogical knowledge, and pedagogical content knowledge in science. Favourable modifications depend on teachers' competencies and support from the system; consequently they depend on sound CPD and ITT. Last, but not least the system must prevent the dilemma of 'null curriculum' in science due to disinterest, or lack of knowledge and proficiency to deal with certain areas of science.

The idea of historical consciousness was presented as a basic conception in this thesis, entailing that if you want to understand what characterizes the transformation of a 'live' phenomenon like the school science curriculum you need to consider it as real duration, and take part in 'construing its past, comprehending its present and encountering and motivating its future' (cf. MESC, 2007b). I consider this a valuable strategy for studying the science curriculum, because it gave me a clearer conception of its nature than I had ever realised.

POSTSCRIPT: THE TRANSFORMATION CONTINUES

It must not be forgotten that the school science curriculum is 'alive' and it will keep transforming in an unpredictable manner. The idea of encountering and motivating the future of the curriculum is at hand. In early 2011 a new general guide for a national curriculum was introduced at all school stages in Iceland, reflecting considerable changes from the policy that had characterised the 1999 curriculum. Although the 1999 curriculum had indicated an inclination to integrate different ideologies, the social efficiency ideology seemed most prominent then, featuring detailed aims and objectives. A social reconstructionist ideology was weakly emerging in chapters about the nature and role of science, but not at all as massively as the new curriculum.

The social efficiency ideology and the scholar academic ideology seem less prominent in the new curriculum, but learner centred and a social reconstructionist ideologies appear to be emphasised, identifying six core issues (i. *grunnþættir*): literacy, sustainability, democracy and human rights, equality, health and welfare and creativity (MESC, 2013). Thus the new national curriculum encourages a vision of a future society that is conceived of as nature-friendly, 'healthier and more human' than the existing one, emphasising human rights, social and economic justice, sustainable development, environmental issues and public health.

The science part of the curriculum (MESC, 2013), labeled 'Náttúrugreinar' in Icelandic (e. *Nature subjects*), features first and foremost responsibility towards the environment, ability to identify one's own position as a critically thinking citizen and the capacity to take actions (i. *geta til aðgerða*). It covers 14 pages with open-ended learning outcomes as criteria for learning, while the 1999 curriculum covered 76 pages with detailed aims and objectives. The learning outcomes in the new draft are divided into two categories, *work procedures* or procedural knowledge (i. *verklag*) focusing on components such as sustainable development, innovation, methods and skills, and *subject matter* (i. *viðfangsefni*) with components like inhabiting the earth, Iceland's nature, and the conjunction of science, technology and social development.

But changes from this might be expected, new 'policy churns', as Richard Elmore (2008) portrayed them. Policy changes sometimes appear as fragmentary ideas, vaguely synchronized with actual practice in schools, quick solutions officially meant to improve the quality of learning and teaching, but hardly ever resulting in long-term betterments.

Now there is certainly a possibility of revolutionary changes of the national curriculum away from the newly presented rationale delineated above with the emphasis on six core issues. Political changes are certainly at hand after a new government came to power recently. Once more the probability of a profound policy churn in education is relatively strong. But what ever happens in politics, we can always assume that a 'Darwinian design' of the curriculum will persist, where favourable modifications will be preserved because they prove advantageous, and Herbert Spencer's prediction that science would form a major part of the intended school curriculum still measures up to all present policies and theories, though it may be contested whether the official curriculum will actually be enacted by its receivers as planned and confirmed in the actual process of teaching and learning. This thesis indicates that schools and teachers are likely to act 'paricularistically' with minor regards to what politicians say or write.

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APPENDIX I

‘Transformation’ of the Science Curriculum

Articles I, II and III - ‘Transformation’ of the Science Curriculum

In this category of research data, effort was devoted to the conception of ‘***transformation***’, and related concepts such as reform, change, innovation, evolution, and curriculum design. Specific features and nature of science education were addressed in that respect.

Article I:
A perspective on the intended science curriculum in Iceland and its ‘transformation’ over a period of 50 years
Þórólfsson, M., Finnbogason, G. E. & Macdonald, M. A.
International Journal of Science Education 2012, *34*(17), 2641-2665

The core article of the study, where criteria based on curriculum ideologies presented in the literature of curriculum theory were applied to analyse the contents of the four national curricula in effect from 1960 to 2010. The study sheds light on the position and function of learners, instructors and subject matter in the learning process of science, and the orientation of content and product versus process and development in the development of the curricula.

Article II:
‘Transformation’ of the science curriculum
Þórólfsson, M.
Rannsóknir í Félagsvísindum (*Research in Social Science*) 2009, X, 701–714

The article sets out to explain the basic conception of the thesis, ‘transformation’, when it is applied to curriculum and its context with related concepts as explained above. It illustrates the difference between virtual reform efforts, deliberately contemplated by parties with vested interests on the one hand, and what might be called a Heraclitean view on curriculum development on the other hand – meaning ‘we can not step into the same river twice’ – or what Daniel Dennett called ‘Darwinian design’ (cited in Papert, 1987, p. 418).

Article III:
‘Transformation’ of the intended science curriculum. A tension between instrumental and liberal purposes
Þórólfsson, M. & Lárusson, E.
Rannsóknir í Félagsvísindum (Research in Social Science) 2010, XI, 205–213

A continuation of Article II, taking into consideration a tension between instrumental and liberal purposes, illustrating the dichotomy of transmitting objective content of science that learners usually need to receive from extrinsic sources and recite (instrumental) on the one hand and the idea of focusing on students as critical human beings and enhancing their informed autonomy (liberal) on the other hand.

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A Perspective on the Intended Science Curriculum in Iceland and its 'Transformation' over a Period of 50 Years[1]

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In recent decades, a consensus has emerged among educators and scientists that all compulsory school students need good science education. The debate about its purpose and nature as a school subject in an emerging information society has not been as conclusive. To further understand this, it helps to examine how the science curriculum has transformed and what forces have shaped it as a core curricular area over time. This article sheds light on the transformation of the science curriculum for compulsory schools in Iceland in force from 1960 to 2010. Using criteria based on curriculum ideologies regarding the function of learners, instructors and subject matter in the learning process and the orientation of content and product versus process and development, it offers findings from content analysis of the intended science curriculum. The official curriculum was studied and conceptualised as it has evolved over time. The curriculum developers appear to have been striving for a compromise between conflicting views, resulting in what the authors of this article conceive as a 'kaleidoscopic quilt' of ideas over the period studied.

Keywords: *Science education; Science curriculum; Intended curriculum; Curriculum development; Educational reform*

The idea of an 'emerging information society' connotes that producing, manipulating and interpreting information, including scientific information, have become critical economic and cultural activities. This study sets out to examine the official science curriculum in that respect; that is, how the national curriculum has addressed the

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purpose and nature of science education in Iceland. Four official curriculum guides were examined and analysed using a framework for analysis based on *underlying ideologies* that shape the curriculum over time (Schiro, 1978, 2008). Thus, the intended curriculum was analysed from two perspectives: first, where the curriculum places *learners*, *teachers, subject matter* and *milieu* in the educational process; second, the emphasis *on content and product* versus *process and development*.

Countries and cultures rely increasingly on proficiency and information related to science and technology; science educators agree that all citizens need to be empowered to apply such information and skills in various contexts. Consequently, science education reforms have focused progressively on promoting what has been called literacy in general science for all learners. In spite of such endeavours, history has taught us that the 'grammar and syntax' of the scientific disciplines do prevail, where school science is perceived 'as a basic preparation for a science degree—in short a route into science. Such curricula focus on the foundational knowledge of the three sciences—biology, chemistry and physics' (Osborne & Dillon, 2008, p. 7).

The ideas of literacy in science may take on different manifestations depending on the curriculum ideology built upon. The purpose of this study is to examine how the intended science curriculum for compulsory education has addressed this problem of promoting scientific literacy and has made efforts to close 'the gap between academic science and science for the citizen' (Hurd, 1998, p. 414).

Iceland and its National Curriculum

Iceland is an island in the North Atlantic Ocean with a population of 319,500 in January 2012 and low population density. The island has been described as an 'open book' for learning science, with its waterfalls, volcanoes, abundant wildlife, geothermal energy, miscellaneous power stations and other approachable phenomena related to natural science and technology. Until the end of the nineteenth century, Iceland was among the poorest countries in Western Europe depending on fishing and agriculture. During the twentieth century, its economy evolved rapidly into highly developed manufacturing systems, featuring service industries, software productions, biotechnology and aspects of the entertainment industry (Statistics Iceland, 2011).

The school system includes preschools for children of ages 18 months to 5 years, primary and lower secondary schools in a single structure (i. *grunnskóli*) for those of ages 6–15 and secondary schools for those of ages 16 − 19. The elementary and lower secondary schools are compulsory, comprising 180 schools with an enrolment of 43,000 students. Official curricula for compulsory education were formally issued in 1960, 1976–1977, 1989 and 1999, revised to a slight extent in 2007. New general guidelines for the national curriculum were approved in 2011 and a draft of subject guidelines appeared in 2012.

Compared with those in other countries, schools in Iceland have considerable autonomy to decide on what to teach and how. According to the TALIS Survey (Organization for Economic Co-operation and Development [OECD], 2009), Iceland is among the highest scoring countries regarding teacher autonomy and decisions on course content and how it is taught. The 2006 PISA data (OECD, 2007) show similar results. Nevertheless, according to law, the official curriculum in Iceland has a status of regulations (Menntamálaráðuneytið [Ministry of Education and Culture] [MEC], 1989) and compulsory subjects such as science are determined centrally by national authorities.

Towards the end of the twentieth century, several research projects concerned curriculum changes in Iceland (Finnbogason, 1995; Jóhannesson, 1991; Kjartansson, 1983; Macdonald, 1993; Macdonald, Pálsdóttir, & Þórólfsson, 2007; Sigurgeirsson, 1992). Most focused on the major reform era commencing in the 1960s and 1970s and its aftermath, when influential scholars argued that 'the maps of learning [were supposed to be] redrawn' as Goodson put it (2010, p. 194). The studies agreed that despite high aspirations, the school system remained unstirred in most parts; the waves created commotion and affected educational discourse, but actual institutional praxis proved remarkably uninterrupted (Macdonald, Hjartarson, & Jóhannsdóttir, 2005).

The transformation of the school curriculum has reflected policy changes both within Iceland and in other countries (Jóhannesson, 1991). As an example, a tangible conflict emerged between two curriculum models in the 1970s and it is still detectable (Edelstein, 2008; Finnbogason, 1995), a conflict between a so-called mechanistic model endorsing programmed curricula and an organic model stressing the natural growth of each learner. The former reflected Tyler's and Bloom's objective approaches and the latter John Dewey's pedagogical ideas on experience and social learning and Jean Piaget's ideas of the cognitive development of learners (Finnbogason, 1995).

The research problems of this study are how official curriculum texts have transformed over time regarding the purpose and nature of science and scientific information and how curriculum ideologies have affected this transformation. This is done by focusing on two research questions:

- How did the curriculum texts present the position of learners, teachers, subject matter and milieu?
- To what extent did the curriculum texts adhere to a content/product model and/or to a process/development model?

Concepts and Conceptions

'Transformation'

'Reform' is a familiar conception in science education (Black & Atkin, 1996). It usually denotes that a system needs improvement, while 'change' implies a more radical alteration. In our case, 'transformation' suggests only that the intended science curriculum evolves over time, but does not necessarily improve or change radically. It might even diminish in effect and become problematic for that matter. Science educators are, for example, aware of the problem that the science curriculum has become 'overcrowded'. New ideas and scientific information keep coming up, but hardly anything is removed (Stinner & Williams, 2003, p. 1027).

Consciousness of History and Time

This study is based on the idea that the science curriculum is a social phenomenon that, *ad infinitum*, keeps transforming. Therefore, it should be studied as being of 'real duration' (Bergson, 1946), ongoing and indivisible, featuring an amalgam of ideologies (Kelly, 2009; Kliebard, 1987; Schiro, 1978, 2008). Thus, this study emphasises the importance of historical consciousness and for clarification it refers to concepts from language research (de Saussure, 1916/1966): *diachrony* and *synchrony.* Diachrony refers to studying changes over time, the intended science curriculum in our case, and synchrony means studying its operation in various contexts by taking cross-sections at certain points of time.

Theoretical Orientation of the Curriculum

Words and their Interpretations

When we theorise about curriculum, we are referring to general principles or ideologies built upon when developing and implementing a curriculum. Such belief systems control education policies and consequently the nature and content of the curriculum (Kelly, 2009; Schiro, 1978, 2008). Perspectives on the curriculum and its nature are reflected by the etymology of words, with the term 'curriculum' referring to a racecourse and 'syllabus' meaning a list of topics to be covered. Students and others with vested interests connect these words with learning programmes to be 'raced through' in schools before examinations: '... for many students, the school curriculum is a race to be run, a series of obstacles or hurdles (subjects) to be passed' (Marsh & Willis, 2003, p. 7).

In general, our view of the intended curriculum reflects such ideas. Normally, it is presented as the national curriculum located at a macro-level, the official plan for learning and teaching, published as a printed or an Internet document reflecting the vision or basic philosophy that education authorities adhere to. The intended curriculum has either a prescribed/obligatory status or an exemplary/voluntary status (van den Akker, 2003) and interpretation varies across users and consequently whether actual learning experiences turn out as intended or not. According to Marsh and Willis (2003), current conceptions of a curriculum in public education would be 'an interrelated set of plans and experiences that a student undertakes under the guidance of the school' (p. 13). Thus, although the curriculum must inevitably be conceived of as *content to be covered* incurring *product to manufacture,* it must also be viewed as a *process to be experienced.*

The Science Curriculum as Content to be Covered

A *content–product*-oriented curriculum focuses typically on facts to know and skills to master. Knowledge is conceived as an end to proceed towards, a product to be manufactured. But when we ask what is to be learnt in school science and how such learning is to take place, it is important to distinguish between 'knowing that' and 'knowing how' (OECD, 2006; Ryle, 1949). It matters whether the science curriculum stipulates that students consider, read about and discuss heat, temperature and thermometers or that students do tasks where they sense heat, detect its effects on different substances and measure temperature with thermometers.

Whether the aim is 'knowing that', 'knowing how' or both, the underlying ideology of a science curriculum focusing on content and product is characterised by a *transmission pedagogy*; the teacher is seen as a transmitter of knowledge and skills practised by adults. Such activities and outcomes are pre-planned by an educational authority. Whether the teaching styles are defined as 'chalk and talk', 'question and answer', 'discovery projects' or 'individualised worksheets' (Goodson, 2005), prescriptive decisions are made for all students, and learning programmes follow predictable patterns.

Two kinds of ideologies support the content–product model of curriculum development (Table 1). Schiro (1978, 2008) labelled the first one as *scholar academic ideology* which aims at transmitting the essence of academic disciplines. Scientific knowledge is envisioned as didactic statements, teaching as transmission of knowledge and the learner as a receiver of knowledge and abilities, a neophyte in a hierarchical community of scholars (Schiro, 2008). Thus, the subject matter in school science is determined and selected from the knowledge bases of disciplines such as biology and physics by specialist scholars, who hand it down to teachers and pupils. 'The curriculum is intended to initiate and acculturate children into a discipline' (Schiro 2008, p. 18). *Scientific literacy* is perceived as adopting the didactic discourse sanctioned by scholars of the discipline, knowing and understanding concepts, methods and laws needed to carry on inquiring into the specialism of the discipline.

The second ideology reflecting a content–product curriculum is *social efficiency ideology* that aims at carrying out a task for society efficiently (Schiro, 2008), providing knowledge and skills that give learners the ability to function in society. Learners are viewed as 'raw materials' to be shaped (Table 1). Education is a social process that is supposed to perpetuate existing social functions and prepare the individual to lead a meaningful adult life in society. *Scientific literacy* is therefore conceived of as acquiring the 'correct' knowledge, skills and manners needed to function in society.

The content–product model construes the learner, and his or her social, cultural and physical milieu, as marginalised; instead attention is directed at the discipline, the teacher and the subject matter and how it is transmitted. Such a curriculum is therefore apprehended as teacher-centred or subject-centred. Historically, a content–product curricular approach follows a systematic planning procedure (Bobbitt, 1918/1928 as cited in Flinders & Thornton, 2009), featuring a mechanistic, behaviouristic and objectives-driven approach (Edelstein, 2008; Finnbogason, 1995; Kelly, 2009). It is often based on the Tylerian rationale (Tyler, 1949), which has been the major ideological source for much curriculum work for the past 60 years, supported by systems such as Bloom's taxonomy of learning objectives (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956; Krathwohl, Bloom, & Masia, 1964),

Table 1. Two kinds of ideologies supporting a content–product-oriented, and subject/teacher-centred curriculum. Based on Schiro (2008)

Scholar academic	*Knowledge*: didactic statements to be transmitted *Learner*: neophyte to be acculturated into a hierarchical community of the academic disciplines, receiver of knowledge *Teacher*: a mini-scholar within the hierarchical community of scholars, transmitting the discipline's content, skills and values to learners	*Scientific literacy*: adopting the canonical discourse of the discipline, i.e. knowing and understanding scientific concepts, methods and laws sanctioned by academic scholars
Social efficiency	*Knowledge*: base for the ability to function in society, defined in behavioural terms *Learner*: an object ('raw material') to be shaped and changed to a finished product, the desired adult to function in society *Teacher*: shapes the behaviour of learners. Director and supervisor of student work according to the curriculum	*Scientific literacy*: acquiring knowledge and skills to function in society

and typically aligned with psychometrics, that is, mainly quantitative methods of assessment aimed at measuring developments of human abilities objectively.

The Science Curriculum as Process and Development

A *process–development-oriented* curriculum is seen as dynamic in nature, 'an attempt to communicate the essential principles and features of an educational proposal in such a form that it is open to critical scrutiny and capable of effective translation into practice' (Stenhouse, 1975). It focuses on the *learning process* and the *learner's development*, allowing for changes at any point unlike the content–product approach where it is considered inappropriate to deflect from initial plans. This approach reflects what actually happens when learners interact with their social, cultural and physical milieu, instead of focusing on prescribed objectives to achieve, content to deliver or schedule to follow. Kelly (2009) portrays the process–development view as a

> ... concern with the nature of the child and with his or her development as a human being. Its purposes are plain, although it has often been accused of lacking clear aims. It sees education as the process by which human animals are assisted to become human beings. (p. 91)

Instead of leaving the learner out of the picture, the process–development approach places him or her at the centre, viewing cognitive development and learning experiences as significant points of orientation. Attention is directed at the learner and his or her milieu rather than at the teacher, teaching and the subject matter; the curriculum is *learner-centred*. Schooling is to be adapted to the learner and the learner's authentic activity is seen as a prerequisite for education (Schiro, 2008). Learners are entitled to education that prepares and empowers them 'for active and productive life within a democratic social context' (Kelly, 2009, p. 91).

A process–development approach in science education supports critical thinking, enquiry and discussion about scientific phenomena rather than acquiring prescribed knowledge, often vaguely related to learners' experiences and milieu. Learners need to understand and realise the structure of scientific phenomena and their meaningful relations to other things: 'Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structured pattern, it is rapidly forgotten' (Bruner, 1966, p. 2). Accordingly, learners need to be active themselves in dealing with problems and discovering structures, the essence of constructivist pedagogy, a view on education that probably had the ascendancy among educational ideologies by the end of the last century (Osborne, 1996).

Two kinds of ideologies presented by Schiro (1978, 2008) comply with the process–development model of curriculum development (Table 2). First, there is *learner-centred ideology*, which Kliebard (1987) identified as developmentalist, assuming that the organisation of learning should be in harmony with children's cognitive stages and personal context. Its aim is to pursue learners' needs and interests and help them make meaning with respect to their prior conditions and knowledge. The teacher is a facilitator of discussion, debate and interaction between learners and their milieu. Learning and teaching are interactive exercises where everyone is learning and growing at his or her own pace. S*cientific literacy* is conceived of as capabilities of learners for growth and understanding of science and its role in their lives.

Second, there is *social reconstruction ideology.* Social reconstructionists aim to reconstruct their culture and facilitate the best conditions with respect to the needs of all

Table 2. Two kinds of ideologies supporting a process–development-oriented and student-centred curriculum. Based on Schiro (2008)

Learner-centred developmentalist	*Knowledge*: personal, based on prior conditions, a derivative of each individual's learning and growth *Learner*: self-activated maker of meaning, learning and teaching interactive exercise *Teacher*: nurtures the growth of learners, provides ideal environments for learning, facilitates learning	*Scientific literacy*: promotion of the learner's growth and understanding of science and its role in his or her life
Social reconstructionist	*Knowledge*: provides the ability to interpret and reconstruct society *Learner*: intelligent, social being whose critical thinking should be promoted. Learning as acculturation into an alleged 'good society' *Teacher*: talks and listens to students as their partner. Helps students analyse and reconstruct meanings in a value-laden context	*Scientific literacy*: promotion of critical thinking and discourse about science and its role in the social context to which the student belongs

subjects of society. Knowledge is supposed to give learners the ability to interpret and reconstruct their society (Schiro, 2008); learning and teaching should stress acculturation into an alleged 'good' society and the learner (the child) is seen as a social being whose nature is defined by the social, cultural and physical milieu in which he or she lives. *Scientific literacy* is conceived of as enhancing critical thinking and discourse about science and its role in the social and political context the student belongs to.

As indicated above, despite endeavours to narrow the gap between academic science and science for all citizens (Hurd, 1998), there is no agreement on one best science programme for all public education. Science literacy for all certainly requires some content knowledge and skills to master, but primarily it calls for critical thinking, flexibility and emphasis on socio-cultural issues. Advocates of the academic disciplines find it hard, on the other hand, to accept organising science learning around socio-cultural issues instead of around the concepts, methods and laws of the sciences themselves (DeBoer, 1991). Consequently, a perspective on the transformation of the intended science curriculum is bound to reflect efforts to reconcile different ideologies of curriculum theory.

The Study

Aims

This study comprises an analysis of the intended science curriculum for compulsory education. Curriculum guides in effect for 50 years, issued by Icelandic educational authorities in 1960 (in force 1960–1976), 1976 (in force 1976–1989), 1989 (in force 1989–1999) and 1999 (in force 1999–2010), were analysed. Criteria identified in curriculum discourse were used to seek answers to the research questions presented above. Thus, the aim was to explore first how the curriculum texts presented the position and role of learners, teachers, subject matter and milieu (Schwab, 1973) and second to what extent they adhered to a content/product model or a process/development model.

The findings are reported for each of the curriculum guides and then discussed with respect to the four ideologies and *scientific literacy* according to those four ideologies: an expected pattern was what Ball (1990) identified as 'a compromise of ideas, needs and interests', that is, a mixture of perspectives.

Method

The contents of the curriculum guides were analysed with respect to aspects of the curriculum as discussed earlier in this article and assessed by a five-point rating scale (Table 3).

The authors began their analysis by discussing the contents of the four curriculum guides and their structure, context and meaning. Attention was directed at the position of learners, teachers, subject matter and milieu. The authors' prior experience

Table 3. Aspects of the curriculum examined and assessed by a five-point rating scale

Characteristics	Emphasis found in each curriculum—range (1–5)
Position of teacher/instruction	1, very weak; 2, weak; 3, moderate; 4, strong; 5, very strong
Position of learner/learning	1, very weak; 2, weak; 3, moderate; 4, strong; 5, very strong
Role of milieu	1, very weak; 2, weak; 3, moderate; 4, strong; 5, very strong
Role of subject matter	1, very weak; 2, weak; 3, moderate; 4, strong; 5, very strong
Content/product	1, very weak; 2, weak; 3, moderate; 4, strong; 5, very strong
Process/development	1, very weak; 2, weak; 3, moderate; 4, strong; 5, very strong

and knowledge of the intended science curriculum and other curricula also helped when discussing and deciding on results. Summaries of findings were drafted and presented as radar graphs based on a rating scale.

Ethical Considerations and Rigour of Findings

The data explored here are official documents, that is, curriculum guides issued by educational authorities, fully accessible for study, so ethical considerations do not concern protection or consent of participants. This study is partly historical as well as a literature review featuring 'data' that others provided and interpretations of those data. To strengthen the rigour of the findings, the data and their internal relations were interpreted with deliberateness.

Therefore, integrity and obligations to the consumers of the research were certainly of concern. Biases were dealt with by reconciling different views through discussion and thus building an inter-researcher reliability. Two members of the researcher team—authors of this article—examined and coded the texts of the curriculum guides independently, with regard to aspects assessed by a rating scale (Table 3). Then, they met with the third author to discuss their analysis and to address possible differences in views and interpretation. Thus, they looked collectively for emerging themes in the data.

Examples of biases were what Strike (2006, p. 58) described as 'intellectual narrowness, judging all work solely by the standards appropriate to one's own paradigm'. Furthermore, we considered what Strike portrayed as 'epistemological pluralism' (2006), that is, taking into account that researchers and scholars may disagree about what should be of central priority and what is worth researching. Finally, we tried to account for a bias called 'presentism' (Gall, Borg, & Gall, 1996), that is, the potential tendency of interpreting past data by using perspectives or concepts belonging to more recent contexts.

Findings—'Transforming' Curriculum Texts

The curriculum guides are official documents, published at the macro-level, entailing that the focus is primarily on rationale, aims and content (van den Akker, 2003), but indirectly on learning activities and pedagogical issues related to the position of the learner and the instructor and the orientation of learning and teaching. In this section, we present the findings for the four curriculum guides regarding criteria depicted in Table 3.

Traditional Nature Studies—The 1960 Curriculum

In spite of some preliminary efforts in the first half of the twentieth century (1903, 1929 and 1948), the first formal national curriculum for compulsory education in Iceland came into effect in September 1960 under the power of the so-called reconstruction government. Its title was *A curriculum for students at the age of compulsory schooling* (Menntamálaráðuneytið [Ministry of Education] [ME], 1960), built on the Educational Act from 1946 and focused mainly on subjects and their contents. According to the introductory chapter, the curriculum had an exemplar status, 'its role is first and foremost to guide teachers and administrators about organising and selecting learning contents' where teachers and administrators 'make sure that each student gets proper assignments according to his or her capability' (ME, 1960, p. 5). The features of the science section are described in Table 4 and Figure 1.

Natural science was addressed in two sections, *Nature studies* and *Local studies*, with the latter also being related to social studies and geography for children up to nine years old. Each subject section started with general aims and was then divided according to the age of the students from 7 to 15 years and according to what was to be taught and learnt in each grade.

The section on nature studies started with general aims concerning the 'instruction of nature studies ... supposed to help students acquire knowledge about the predominant phenomena of nature, focusing on what they need to know with respect to daily

Table 4. Features of the intended science curriculum 1960

Form	A section of the whole intended curriculum, which was issued in one book
How presented	Science presented as 'Nature studies' (i. *Náttúrufræði*) and part of 'Local studies' (i. *Átthagafræði*)
Proportion of whole curriculum	8 pages of 84 (9.5%)
Rationale	No clearly stated vision or rationale. Focus on knowledge in zoology, botany, physiology, hygiene, physics and chemistry. Understanding of wildlife conservation mentioned
Aims/objectives	General aims, but no measureable objectives
Content	Topics presented like a catalogue
Pedagogical issues	Ideas about learning and teaching in a special supplement, *For further review*, but not in the main curriculum section
Other characteristics	Nature studies section divided into short chapters according to the traditional nature subjects, botany, physics, zoology, physiology and chemistry

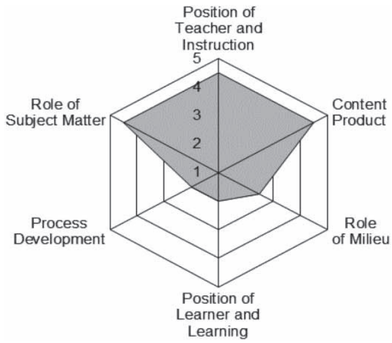

Figure 1. The intended science curriculum 1960. Characteristics examined and assessed by a five-point rating scale (cf. Table 3)

life' (ME, 1960, p. 41). Following the general aims were sub-chapters about zoology, botany, hygiene, physiology, physics and chemistry assigned to grades. The sub-chapters resembled a catalogue of topics to be *taught* at each stage, for example, about the characteristics of mammals, birds, fish and other animals and their body structures and offspring and about plants and their structure. Physics and chemistry instruction did not start until the seventh grade (13 years old). It featured the same catalogue approach focusing on *teaching* concepts and laws of science, for example, forces, gravity, magnets, electricity, compounds, elements, molecules, atoms, acids, combustion, corrosion and distillation. The catalogue did not indicate learning outcomes in terms of learner competence or performance; instead it comprised topics to be taught.

The section on nature studies seemed mostly *subject* and *teacher-centred*, specifying what should be taught and when (Figure 1). The curriculum even indicated where exceptions were allowed: 'Where it is considered more convenient, schools have permission to teach zoology and botany in 7th grade and physics and chemistry in 8th grade' (ME, 1960, p. 44). It was *content-product-oriented*; the contents of the subject were to be transmitted, providing learners with the knowledge and ability to function in society. Teaching was to involve conditioning behaviour, where learners should be 'shaped', and although assessment was not accounted for, it could easily be understood as gathering data about the achievement (product) of learning.

At the end of each section in the curriculum, there was a supplement section called 'For further review', with recommendations about the learning process, stressing the importance of relating new knowledge to prior learning, using the natural environment of the school as subject matter and appreciating the conservation of nature and wildlife. There were suggestions about hands-on learning and that students discuss and present their work orally and in writing.

Local studies for children of ages 7–9 had an interdisciplinary nature, emphasising children's knowledge about their environment and awareness of their personal and social development: '[In local studies] children are brought into a world ... not in such a manner that they feel they are being instructed about it, but rather as if life itself unfolds for them through their own activities and observations' (ME, 1960, p. 28). So, the 1960 curriculum was not solely under the influence of content–product ideologies. Pedagogical theories of child development and consequently the learner-centred ideology were detected, even early signs of social constructivist learning models.

Fundamental Change—The 1976 Curriculum

The 1960s and 1970s were times of turmoil, 'hippie' times, featuring 'a whole generation with a new explanation' (Phillips, 1967). In education, these times were controversial, where educators debated almost anything, from aims and contents of learning to the organisation of school environments.

The impetus of the new explanations and controversies in education came from distinct sources, such as Jean Piaget's and Lawrence Kohlberg's developmental psychology, Bourdieu's and Passeron's sociological research and Jerome Bruner's ideas about the process of education (Finnbogason, 1995; Indriðadóttir, 2004; Jóhannesson, 1991). In the late 1960s, two official committees, one on physics and chemistry (ME, 1968) and the other on biology (ME, 1969), made recommendations about the reform of natural science in the official curriculum. The authors were apparently under the influence of the major reform wave that originated in Western education in the mid-1950s (Macdonald, 1993; ME, 1968, 1969) under the label of 'new science' (DeBoer, 1991).

This was also the heyday of curriculum theories such as Tyler's rationale, Taba's ideas of curriculum planning and Bloom's taxonomy of learning objectives. Innovative approaches to social studies and the 'new science' wave flooded the world. In 1974, new legislation on education came into force in Iceland, more detailed and developmentally oriented than before, and new curricula were prepared and released in 1976 and 1977 in 10 booklets under the rubric of *The national curriculum for compulsory schools* (i. *Aðalnámskrá grunnskóla*). Intensive in-service training followed in many subject areas (Macdonald, 1993).

Biology and physical science were separated, where the latter included physics and chemistry. Earth science had not yet obtained its place in the science curriculum. The features of the 1976 science curriculum are described in Table 5 and Figure 2.

The physical science curriculum was formally issued in September 1976 (ME, 1976); the biology part was never formally completed, but existed as a draft of 11 pages, a copy of which was found in the Ministry's archives (ME, n.d.). Although its ideology came into effect a decade later than in countries such as the UK and the USA, the emergence of the 1976 physical science curriculum in Iceland had characteristics similar to those of the reform movements that permeated Western education systems in the 1960s and 1970s. The reform of the curriculum was led by subject specialists and scientists who cooperated with teachers and educational theorists. Large amounts of money, time and expertise were spent in developing science education materials according to the new curriculum (Helgason, 1972). Both the

Table 5. Features of the intended science curriculum 1976

Form	The whole curriculum comprised 10 booklets
How presented	Physics and chemistry (i. *Eðlis- og efnafræði*) and biology (i. *Líffræði*). Earth science had not yet reached the science curriculum
Portion of whole curriculum	Physical science 15 pages and biology (draft not published) 11 pages of 465 (5.6%)
Rationale	No clearly stated vision or rationale, but focus on knowing and understanding basic ideas in physics, chemistry and biology
Aims/objectives	General aims and to an extent measureable objectives
Content	Topics reflected through comprehensively phrased aims and objectives
Pedagogical issues	Ideas about learning and teaching limited to methods and discourse of science and scientists
Other characteristics	The physical science curriculum reflected scientific purism, with negligible connection to a student's everyday milieu

new materials and in-service training coupled and were part of the new official vision and thus belonged to the intended curriculum. They were supposed to have an impact on learning and teaching and thus implement ideas from projects such as the PSSC, BSCS and CHEM projects in the USA and the Nuffield projects in the UK (Macdonald, 1993).

The curriculum of 1976, especially that of physics and chemistry with its learning materials, teaching approach and use of experimental equipment, was abstract in nature, conceptually and cognitively sophisticated, and detached from the natural milieu of students (Figure 2). Pupils aged 11–12 were supposed to practise and get acquainted with measuring equipment as a preparation for more sophisticated work and studies at the lower secondary stage.

The 'new science' curriculum actually expected teachers and students to think and act like scientists or, as Bruner argued in his monograph about the Woods

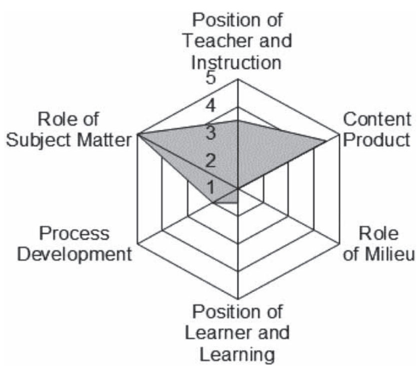

Figure 2. The intended science curriculum 1976 (Physical science). Characteristics examined and assessed by a five-point rating scale as indicated in Table 3

Hole conference: 'The schoolboy learning physics is a physicist, and it is easier for him to learn physics behaving like a physicist than doing something else' (Bruner, 1966, p. 14). According to the curriculum guide, 'now the student's activity in seeking knowledge is considered more important than acquiring bits and pieces of knowledge' (ME, 1976, p. 6) and 'gradually the requisition for more knowledge and understanding increases, and more independence in methods of work, e.g. when processing data, designing tables and graphs, interpreting outcomes and applying them when resolving new problems' (ME, 1976, p. 7). The detailed objectives reflected how content and subject matter had a central status, where students were supposed to know and experiment with phenomena such as Newton's laws, forms of energy, structure of matter, waves, Boyle's law and Ohm's law.

Integration and Holistic Development—The 1989 Curriculum

In the 1980s, ideas about open education, curricular integration and creative learning in classrooms without walls, mirrored the political changes that commenced in the 1960s under the label of child development. The message was clear; for example, in the British Plowden report (Gillard, 2011), and echoed all over the Western educational world: 'No whole-class lessons, no standardised tests, and no detailed curriculum' (Cuban, 2004). The 1989 curriculum in Iceland (MEC, 1989) had antecedents reaching back to the 1970s, but its final version reflected some ideas of an open curriculum. It was not a detailed curriculum promoting aims and contents of traditional subjects; rather it endorsed transferring power to teachers to select content and organise learning according to the context and needs of learners. The features of the science section are described in Table 6 and Figure 3.

Table 6. Features of the intended science curriculum 1989

Form	A section of the whole intended curriculum, which was issued in one book
How presented	As 'Nature studies (physics, chemistry and biology)' (i. *Náttúrufræði (eðlis-, efna- og líffræði)*), for the first time assigned to all grades of compulsory schooling as one integrated school subject (general science)
Proportion of whole curriculum	10 pages of 196 (5.1%)
Rationale	Central focus on whole child development, the importance of learner-friendly milieu, thematic learning and integration of subjects
Aims/objectives	General aims, but no measureable objectives
Content	Topics presented and described in general wording
Pedagogical issues	Strong emphasis on pedagogy and child-centred ideology
Other characteristics	Traditional nature subjects, such as botany, zoology and physiology, had receded, while focus on environmental issues and technology was more visible

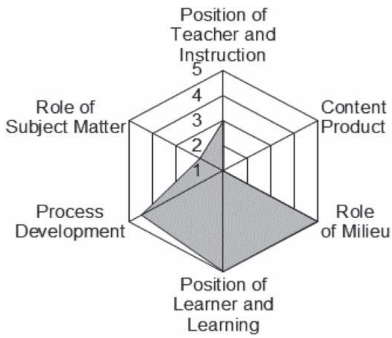

Figure 3. The intended science curriculum 1989. Characteristics examined and assessed by a five-point rating scale as indicated in Table 3

The idea of integration was accentuated, so the message was that natural science should intertwine with other subjects focusing on thematic learning where the 'boundaries between subjects [were to be] blotted out' (MEC, 1989, p. 32).

The curriculum featured a holistic perspective on learning, viewing each learner more or less as a unique, self-actuated maker of meaning, with his or her specific individual needs with respect to cognitive, aesthetic, emotional and social development: 'The compulsory school should endeavour to organise its work according to each student's character and needs and promote the overall development of each individual' (MEC, 1989, p. 13). The 1989 curriculum was mainly *process and development*-oriented (Figure 3), seeing science learning as acculturation into a milieu-friendly culture, stressing each learner's interests, intrinsic motivation and respect towards natural phenomena.

The disciplinary focus on science education featured in the 1976 curriculum was now taken with a degree of scepticism and the 'impact of those sciences on our way of living and our world view' was highlighted as an issue (MEC, 1989, p. 106). The need to consider man's efforts to exploit nature and change the environment was intriguing: 'Natural science and technology are among the most important preconditions for our way of living, but also what endangers our future most of all' (MEC, 1989, p. 106). Additionally, there was an emphasis on inquiry learning and that students work together on science projects exploring big ideas and whole contexts in their natural milieu. The 1989 curriculum still encouraged the acquisition of scientific knowledge and skills to a certain extent as though advocates of the disciplines (physics, chemistry and biology) resisted too much innovative endeavour.

Mixed Ideologies—The 1999 Curriculum

As soon as the 1989 curriculum came into effect, voices of criticism began to be heard, mostly that the curriculum was considered too open-ended and needed standardisation with respect to objectives of the academic subjects (Committee on Educational Policy,

Table 7. Features of the intended science curriculum 1999

Form	Separate booklets. The whole curriculum comprised 12 booklets
How presented	Titled 'Nature studies'. In the curriculum text, either portrayed as 'nature studies' (i. *náttúrufræði*) or 'natural science' (i. *náttúruvísindi*), with subsections titled physical science, life science and earth science
Portion of whole curriculum	76 pages of 930 (8.2%)
Rationale	A mixture of ideologies. But clear objectives and contents of scientific disciplines echoed consistently throughout the curriculum
Aims/objectives	General aims and clear objectives
Content	Topics presented and reflected clearly through aims and objectives
Pedagogical issues	A mixture of behaviourist and constructivist ideas about learning
Other characteristics	Earth science for the first time part of the science curriculum. Three main areas addressed: nature and function of science; content of science (physics, earth science and biology); methods and skills

1994; Sigþórsson & Eggertsdóttir, 2008). As the end of the century approached, educational rhetoric reflected familiar ideas such as goal-steering, accountability, measurement, decentralisation and standardised testing, endorsing individualism and competition. This was in harmony with contemporary neo-liberalist views that characterised educational discourse in Western countries during the last decade of the twentieth century (Ball, 2007). From 1991 to 2008, the Ministry of Education, Science and Culture was governed by the liberal conservatives who started the reform process as soon as they came into power (Committee on Educational Policy, 1994). Over the period 1996–1999, an enormous effort was put into a comprehensive reform, resulting in 12 new curriculum booklets for compulsory education covering almost 1000 pages of detailed aims and objectives. Over 200 specialists took part and numerous representatives of political parties and interest groups were consulted. The features of the science curriculum are described in Table 7 and Figure 4.

This was 'the beginning of a new chapter in the history of education in Iceland' (Menntamálaráðuneytið [Ministry of Education, Science and Culture] [MESC], 1999a, p. 5), where a standards-based curriculum was presented, comprising an amalgam of principles and ideologies discussed in this article. The message appeared to be that instruction should be based on a behaviouristic, objectives-driven curriculum, but teachers should work according to constructivist ideas (Macdonald, 2000). The message about clear and objective learning outcomes was conclusive:

> Clear objectives are a basic premise for school operations. The objectives serve as a guide for all school operations and as the basis for planning study and instruction. They direct both instruction and evaluation and are the basis for evaluation of the quality of school operations. (MESC, 2004, p. 24)

Each subject in the 1999 curriculum provided guidelines at three levels: final goals, intermediate aims and detailed learning objectives for each grade. The science curriculum addressed three areas: the nature and function of science, science content

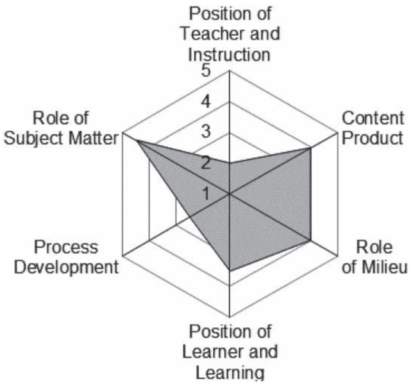

Figure 4. The intended science curriculum 1999. Characteristics examined and assessed by a five-point rating scale (see Table 3)

(drawn from physical science, earth science and biological science) and methods and skills (MESC, 1999a). Final goals for compulsory education in science were presented at the end of the introductory chapter. Then, aims were provided in three sections, for first to fourth, fifth to seventh and eighth to tenth grades, together with detailed objectives in the content areas for each grade.

One of the authors of this article remarked that reading the 1999 science curriculum 'felt like examining a quilt pattern with diverse designs' (Figure 4).

Aims and objectives from the content areas (physical science, earth science and life science) covered 41 pages (54% of the text). The introduction was clear with regard to the science disciplines:

> A solid understanding of the nature of the disciplines and their role within modern society, knowledge of principal laws and predominant theories, along with certain skills in scientific working procedures, are considered important elements in young people's development and education. (MESC, 1999a, p. 7)

But other views were also observed: 'Students should perceive science education as a process and a creative exercise rather than acquiring specifically defined knowledge and proficiencies' (MESC, 1999b, p. 11).

Discussion

The results of this study demonstrate that the focus on instruction as knowledge transmission has gradually decreased since 1960, where the position of the teacher was assessed as strong, but in the 1999 curriculum it was assessed as weak. The position of learning and milieu had changed, on the other hand, from being very weak in the 1960 and 1976 curricula to being strong in the 1989 and 1999 curricula. The position of subject matter has generally been strong, except in the 1989 curriculum, where it was

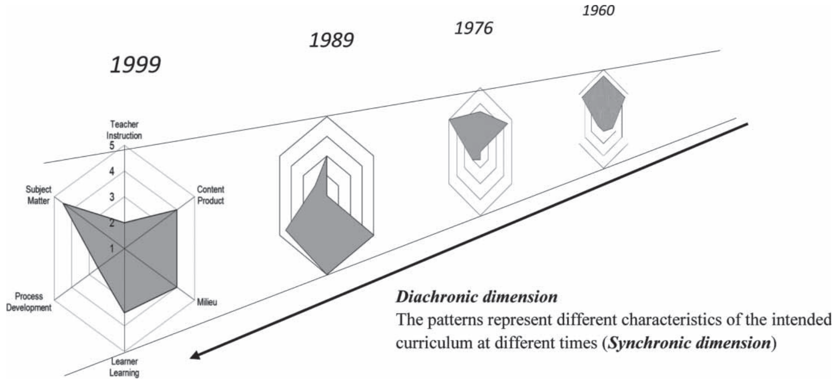

Figure 5. The intended science curriculum that transforms constantly. Studying the curriculum accounts for changes over time (the diachronic dimension) and status at a particular point of time (the synchronic dimension) (based on Widdowson, 1996)

judged weak. In a similar vein, the content–product model appears stronger than the process–development model in all the curricula, except in the 1989 curriculum.

The intended science curriculum transforms constantly regarding the above characteristics and in turn with respect to the underlying ideologies that shape it over time (Figure 5).

In our context, an ideology refers to general principles built upon when developing and implementing a curriculum. History has taught us that such principles tend to conflict with each other and our study seemingly affirms this. The 1960 curriculum appeared to favour the social efficiency ideology that emphasised knowledge and skills to function in society, but by the end of the 1960s, different ideas began to emerge. In 1968, a committee on physics education firmly declined such 'practical issues' as the 1960 curriculum called for, featuring a 'stagnant society' (ME, 1968, p. 14). Instead, the committee recommended knowledge and skills from modern physics, according to the scholar academic ideology. In the 1980s, environmental and ecological concerns emerged intertwined with the learner-centred ideology as reflected in the 1989 curriculum stressing the position of learners and their milieu.

The 1989 curriculum gave an impression of compromise between perspectives. Although it promoted learner-centred ideology and the social reconstructionist view seemed moderately strong, the academic disciplines were observable as the explanatory heading indicated, 'Nature studies (physics, chemistry and biology)'. But they were less articulated due to inexplicit, open-ended goals and they were more socially oriented than scholar academic theorisers would accept.

The 1999 curriculum, on the other hand, indicated an inclination to integrate different ideologies, implying that they are archetypes or ideal models rather than actual beliefs and practices of educators, so it would be more reasonable to view real practices as 'approximations of the ideal types ... a combination of the characteristics of more than one ideal type' (Schiro, 2008, pp. 11–12). Although the social efficiency ideology seemed most prominent in the 1999 curriculum according to our analysis, featuring detailed aims and objectives, the learner-centred view featuring process and development was also evident, underpinning creative exercises according to each learner's interests and a process model of learning science. The social reconstructionist ideology was found under aims concerning the nature and role of science. Furthermore, the scholar academic ideology was also observed by reason of the concise classification of content and objectives according to the academic disciplines. So, the 1999 science curriculum appeared as a 'quilt pattern', an amalgam of ideologies. And there were even concerns about whether the curriculum could 'seriously and with good conscience present detailed objectives and simultaneously encourage teachers to teach according to constructivist theory' (Macdonald, 2000).

The history of life science in Icelandic curricula is worth paying attention to. The 'Nature studies' section of the first formal curriculum issued in 1960 included topics from both the biological and the physical sciences, but life science had not reached its status as a unitary subject; instead it was divided into zoology, botany, physiology and hygiene. According to Goodson (1996), biology as a self-contained discipline first started to earn its place in general school curricula with the development of molecular biology, which did not find its place in Icelandic curriculum discourse until the late 1960s (Macdonald, 1993; ME, 1969). Though the biology curriculum itself never reached publication in 1976, new learning materials, for example, the molecular (blue) version of BSCS materials from the USA, were translated and issued, allocating teaching and learning to the understanding of the logical structure of an academic discipline. Despite the academic focus, the draft of the life science curriculum guide seemed more learner-centred than the physical science curriculum, emphasising holistic development of the learner and a 'sociocultural' view, arguing that most projects in biology learning 'are more productive when students collaborate … a more developed student benefits a great deal from explaining his or her ideas to schoolmates …' (ME, n.d., pp. 10–11). When one of the authors taught science in an Icelandic lower secondary school in the late 1970s, teachers were using a hodgepodge of various learning materials, old books featuring the classification of plants and animals, on the one hand, and the newly translated BSCS materials offering a quite different perspective, on the other hand. Life science in the 1989 curriculum mainly comprised environmental and health-related issues with a non-academic focus, and despite endeavours to establish a sound base for biology in the 1999 curriculum, its weakness consisted of the fact that the curriculum had become 'a crowded place' as Stinner and Williams (2003) phrased it, with a myriad of other aims and objectives related to physics and earth science and the role of science and technology in our society.

The constant transformation of the science curriculum presumably has two main explanations: first, the tendency of the intended curriculum not to remove items and topics to make space for new ones; second, the dilemma of providing science education for all and at the same time meeting the needs of those who seek academic knowledge and skills and choose to continue studying science to advanced stages (Millar & Osborne, 2006). Some school systems have tried to resolve this tension by offering a core curriculum with an emphasis on scientific literacy for all in lower levels and then general science courses alongside optional traditional science subjects that are offered at higher levels (De Vos & Reiding, 1999; Millar & Osborne, 2006).

The general notion of literacy in science for all citizens is by no doubt considered essential in public education. Even though the phrase 'scientific literacy' was not found in the curriculum texts analysed in this study, the curricula did address competences of diverse kinds that can be regarded as science education for all and a push towards what has been defined as literacy in science. Besides knowing and understanding scientific concepts and methods, scientific literacy also requires 'linking together ideas from a range of experiences of real phenomena, problems and events' (Harlen, 1996). The PISA 2006 framework portrayed this complexity by introducing four components of competences (OECD, 2006): first, *knowledge of* science; second, *knowledge about* science; third, identifying scientific matters in various *contexts* (*personal, social* and *global*); and fourth, *attitudes towards* science (*interest, support* and *responsibility*).

Connecting these with the curriculum texts that were analysed in this study, the *knowledge of science* component was clearly emphasised in the 1976 curriculum (Figure 2). The physical science curriculum was deceptively abstract in nature and detached from student interests and lives, stressing canonical discourse of the discipline and knowledge of concepts, methods and laws sanctioned by academic scholars. The draft biology curriculum also stressed knowledge of life science, but it was more focused on context and featuring environmental literacy. Knowledge of science was also fairly strong in the 1960 curriculum and the 1999 curriculum, focusing on the acquisition of knowledge and skills to function in society, but minimal in the 1989 curriculum.

The *knowledge about science* component, stressing scientific enquiry and explanations, was accounted for in the 1999 curriculum under the areas 'About methods and skills' and 'The nature and role of science'. The process approach was also stressed in earlier curricula, especially in the 1976 curriculum, which was strongly influenced by enquiry and discovery learning: 'Students practice measuring and systematic observation ... apply knowledge, interpret results from observations, formulate hypotheses and test them, and use their knowledge and understanding in resolving new problems' (ME, 1976, p. 5).

The *contexts* component refers to understanding personal, social and political issues, such as health issues, climate change, sustainability, extinction of species and the overall influence of science and technology on our lives. This was addressed in the 1989 curriculum by promoting critical thinking and discourse and an effort to humanise science education focusing on 'sympathy towards life, nature and the environment ... [encouraging] attitudes towards conservation of nature' (MEC, 1989, p. 106), an ideology reflecting a social reconstructionist view. The 1989 curriculum had more connection to the science–technology–society (STS) theme than to scientific literacy. The STS theme conveys science as a human endeavour where human feelings and emotions receive more attention than knowledge of concepts and intellectual skills (DeBoer, 1991). The 1999 curriculum also emphasised contexts referring to the application of scientific and technological knowledge and understanding its importance in our daily lives. The area of the 1999 curriculum 'About the nature and role of science' also refers to the *attitudes* component of science literacy, emphasising positive attitudes towards science, interest in the field and support and responsibility towards resources and environments.

Conclusion

The transformation of the intended science curriculum was explored in this study. We considered the idea of historical consciousness important in such contexts, because everyone takes part in this transformation striving to 'construe the past, comprehend the present and encounter and motivate the future' (MESC, 2007, p. 15). The curriculum itself is dynamic; it transforms *ad infinitum* to accommodate the needs and requirements of the system at particular points of time. To illuminate this further, we have referred to concepts borrowed from language research: synchrony and diachrony (Widdowson, 1996) (Figure 5). As Widdowson explained, language development is dynamic; it never stops evolving. The science curriculum is similar. Transient ideologies keep shaping its structure and nature; new ideas and perspectives come up, while hardly anything is displaced. Thus, we have compared the transforming curriculum with a 'kaleidoscopic quilt', a kaleidoscope referring to ever changing images and ideas and quilt suggesting that the curriculum reflects an integration of different ideologies. Furthermore, Widdowson (1996) pointed out that synchrony must not be understood as stability: 'Wherever you take a synchronic slice ... you will find not fixity, but flux' (p. 22). In the same manner, we consider the curriculum not just as changing over time. It also reflects fluctuation at specific points of time, in particular when it is considered from a broader perspective, that is, if the implemented and attained curricula were taken into account.

We keep climbing on new bandwagons, striving to 'encounter and motivate the future'. New general guidelines for the national curriculum in Iceland were approved in 2011 and a draft of subject guidelines appeared in 2012. This time the *social reconstruction ideology* appears to predominate for the first time, although other ideologies can also be detected. The new national curriculum encourages a vision of a future society, that is, 'healthier and more human' than the existing one, emphasising human rights, social and economic justice, sustainable development and public health (MESC, 2011). A draft of the science curriculum (MESC, 2012) testifies that besides knowledge and skills, the emphasis will be on

> attitudes towards nature, technology, society and environment ... learners should be supported in analysing and assessing their own positions and competences, improve their own literacy, moral strength, feelings and creative potentials ... science learning should help students realise what they know and what they are capable of, and know how to apply their knowledge and skills successfully to influence their environment and improve it. (MESC, 2012, p. 2)

Acknowledgements

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Note

1. This article reports on findings that are part of two larger studies called *Transformation of the science curriculum in Iceland* and *Intentions and reality in science and technology education*. The former is the first author's doctoral project at the University of Iceland and the latter is a research project funded by The Icelandic Research Fund (i. *Rannsóknarsjóður Íslands*).

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‘Transformation’ of the Science Curriculum

Meyvant Þórólfsson

Transformation of the science curriculum denotes that it changes markedly in character and nature, presumedly for the better. This article describes the theoretical framework and rationale that underlie a study on the ‘transformation’ of the science curriculum in Icelandic public education. All levels of the education system are viewed in perspective, taking into account that changes in one level do not nessecarily promote changes in other levels consistently.

Besides transformation, two related concepts, *diachrony* and *synchrony,* are taken into consideration in this research, purporting that curriculum is a dynamic phenomenon, not a static one, steadily passing through complex processes to accommodate diverse ideas and needs. Albeit reform periods seem to occur as cycles, we will never be able to experience the same scenario twice in real practice. Diachrony and synchrony are well known concepts from studies of human language. The Swiss scholar, Ferdinand de Saussure, proposed that language studies should account for changes of language over time (Widdowson, 1996), i.e. *the diachronic dimension*, and its status or cross-section at particular points of time, i.e. *the synchronic dimension*. Nevertheless synchrony should not be confused with stability: ‘Wherever you take a synchronic slice through language you will find not fixity, but flux. This is because language does not just change *over time*, but varies *at any one time*’ (Widdowson, 1996, p. 23)

‘Transformation’ implies that the science curriculum changes constantly over time and features ‘not fixity, but flux’ at any one time as goes for language development. The same applies to terms like ‘educational reform’, ‘educational change’, and ‘educational progress’. Their meanings are conditional and they are often used interchangeably (Horn, 2002). But the rationale of the study demands that their different meanings and implications are perveived in context. The term ‘reform’ implies that a system supposedly needs improvement and new solutions are offered, while ‘change’ implies that it will be altered. 'Progress' should be conceived as a constant evolvement or advancement without preconditions, such as growth or improvement. Curriculum is evidently a dynamic phenomenon and its development is 'steady work' (Elmore & McLaughlin, 1988) where improvement is never guaranteed.

Table 1. Three integrated components comprising the design of the study

Component 1	Historical documents	Investigation and analysis of written documents, papers, records, reports, recommendation papers, memos etc.
Component 2	Oral history research	Interviews with subjects involved in the evolution of the science curriculum
Component 3	Present curriculum work	Collection of current data with mixed methods in collaboration with other researchers in science education

The design of the study, which is a basis for a doctoral thesis, consists of three integrated components (Table 1), an analysis of historical documents related to the evolution of the science curriculum, oral history research consisting of interviews with subjects that have been involved in the evolution of the science curriculum and gathering data about present curriculum work in science education. The three components are intended toprovide an integral view of the transformation of the science curriculum. The theoretical framework for the study covers three conceptions: *Curriculum reform*, *Curriculum theory* and *Science curriculum*

Curriculum reform: 'We can not step into the same river twice'

Educational reforms are usually meant to bring solutions to problems, or offer new opportunities and resources. They vary in scale and origin (Walker & Soltis, 1997) but they are typically top-down processes from system level policy formation to implementation in the classroom level. Some are particular whole-school reforms and some are more systemic reforms affecting communities or the nation as a whole. Reforms can originate from groups of any kind, politicians, scholars, unions or business executives (Walker & Soltis, 1997). Whether they are large-scale or small-scale we assume that they may affect everyone associated with education – students, teachers, parents, school officials, government agencies, textbook publishers, and more.

It has been argued that natural science is the most revised of established curricular areas, 'at least in respect of proposals for reform' (Donnelly, 2006). Its definition and role have changed from one time to another which inevitably has raised controversies. Ever since natural science became part of mainstream education in the nineteenth century the science curriculum has undergone constant transformations with respect to content, structure, conceptual framework and underlying philosophies (Atkin & Black, 2003; DeBoer, 1991). This gives the impression that teaching and learning in science supposedly change distinctly in a similar fashion as transformation happens in the natural world, for example when a butterfly emerges from a chrysalis; it transforms its nature and how it functions in real life settings by passing through recurring cycles. Does the science curriculum undergo similar transformations?

The literature actually affirms (Fullan, 2001; Elmore & McLaughlin, 1988; Tyack & Cuban, 1995) that educational rhetoric does seem to pass through such recurring cycles. But it states also that we need to distinguish between predominant ideologies and rhetoric on the one hand and real practice on the other. When we claim that the science curriculum undergoes constant changes, with ideas appearing as recurring cycles, it applies more likely to discourse and ideas than real practice. Similarly we need to consider which level of the system is at issue because real change applies more likely to the ideal curriculum or rationale than the implemented curriculum. The prescribed curriculum may change regularly, but marginal changes are more probable in real-life classrooms (Elmore & McLaughlin, 1988). Furthermore the metaphor of the cycle is not valid for real-life settings in education because it means returning to the same place and situation again and again, 'seemingly denying the possibility of progress' (Tyack & Cuban, 1995).

Tyack and Cuban´s metaphor of 'tinkering toward Utopia' (1995) might therefore be more proper to describe science education reform at the school level than actual transformation as found in the natural world. The word tinkering has a derogative meaning, giving the impression that reformers fiddle with the complex system we call school without realizing how it functions and therefore not anticipating the consequences of their tinkering. Utopia as Thomas More presented in his novel five centuries ago was as an ideal system, actually an unrealistic ideal, impossible to achieve. Tinkering towards such an ideal may therefore seem like pursuing unattainable ends, goals not capable of being accomplished.

Real school practice embodies complex settings that are typically 'particularistic' (Elmore & McLaughlin, 1988) and unique with respect to culture, context, space and time, which means that each school, learner and teacher functions in an unpredictable manner and their interactions vary significantly (Fullan, 2001; Elmore & McLaughlin, 1988). Due to the complexity of school structures and diverse practices at the classroom level an external pressure for change may imply a positive experience for a given situation while it may bring a negative experience for another (Walker & Soltis, 1997; Elmore & McLaughlin, 1988). Ultimately, outside interventions are doomed to fail in bringing solutions that work for every setting. Each school and classroom must learn and develop in context because of the uniqueness of their situation (Fullan, 2001) and the effects on schools, learners and teachers will therefore vary significantly.

Progress is a physical fact, 'we can not step into the same river twice' and the definite direction of time enables us to remember the past and never experience it exactly the same way over again. Although the past is unattainable we are able to study it and diagnose previously experienced problems and learn from them, which implies that using the cycle metaphor is in fact irrational (Tyack and Cuban, 1995). Another important issue of concern is the fact that we live in an increasingly disordered and chaotic world; or as Stephen Hawking has attested (1998) with his conception of the thermodynamic arrow of time, a measure of an increasing disorder of the world, along with the psychological and the cosmological arrows: The essence of our existence precludes history from repeating itself.

Every time a new era begins, the stage will inevitably be different from before. Constructivist pedagogy is for example certainly not a new conception in education. Although constructivist pedagogies concerned with science learning in the beginning of the 21st century draw on the writings and work of Lev Vygotsky, John Dewey, and many other thinkers of the early 20th century progressive era, it is apparent that the context is different today from what it was before. 'While the names of the authors are the same in both periods, contemporary school reforms exist within an amalgamation of institutions, ideas, and technologies that are significantly different from those of the turn of the [20th] century' (Popkewitz, 1998).

The unprecedented multinational wave of science curriculum reform that started in North America in the mid-1950s and lasted for at least two decades was an intriguing example of a major large-scale curricular reform (DeBoer, 1991). With federal involvement in allocating science teaching and learning to the logical structure of the academic disciplines and the process of science, the 'new science' expected teachers and prominently students to think and act like scientists. Through two officially appointed committees on science education in Iceland (Menntamálaráðuneytið, Skólarannsóknir, 1968; Menntamálaráðuneytið, Skólarannsóknir, 1969) this new wave had an immense impact on Icelandic science education in the late 1960s and 1970s (Ingólfur Jóhannesson, 1991; Macdonald, 1993), especially the national curriculum and the edition of learning materials based on the PSSC, BSCS and CHEM projects from America and the Nuffield project from England.

According to Paul DeHart Hurd (as cited in DeBoer, 1991) the 'new science' reform wave embodied a number of strengths and advantages for public education, such as promoting inquiry learning, focusing on significant concepts in depth and in context and being less concerned with coverage. But there were intensive weaknesses and disadvantages, such as the abstract nature and theoretical sophistication of the curriculum, ignorance of science in the social world and everyday life of students and little effort in developing students' interest in studying science.

The end of the 'new science' wave was characterized by a new theme that brought out the relationship between science, society and technology, and the integration of science with other human interests: Scientific literacy, science for all and science for citizenship. A new wave of science curriculum reform was emerging:

> Rebuilding school science will require us to recognise that in a citizen's science, knowledge should be concidered functionally, in terms of its social purpose...Constructing a science curriculum for the citizen demands a new understanding of scientific capability and new view of the nature of science and values in science. These are issues which have hardly reached the shores of Iceland...(Macdonald, 1993, p. 18–19).

Curriculum theory: ‘Conflicting Visions on Educational Experience’

Theorizing about curriculum connotes seeking answers to fundamental questions like what should be the purpose of the school, what should be taught and learned, how and why, what counts as legitimate knowledge, and how to administer and organize the school environment and its context. ‘Educational experience’ is a key concept in this perspective. One of four key questions in Tyler´s rationale (Tyler, 1949) was: ‘What educational experiences are related to those purposes [of the school]?’, i.e. what subject matter, learning problems, educational challenges, ideas, values, learning environments and learning conditions are of most relevance?

According to curriculum specialists the quest for answers to such questions is best described as warfare (Kliebard, 1986; Schiro, 2008). Schiro describes this search as a perennial war between educators over what the nature of the school curriculum should be. He prefers to use the word ‘ideology’ instead of the more common term philosophy for ‘curriculum visions, philosophies, doctrines, opinions, conceptual frameworks, and belief systems’ that control education policies. He also points out that all curriculum ideologies represent ideals ‘abstracted from reality, and not reality itself’ (Schiro, 2008, p. 12). As Kliebard (1996) did in his historical overview of curriculum philosophies, Schiro (2008) depicts four major curriculum ideologies, *the scholar academic ideology the social efficiency ideology*, *the learner centered ideology*, and *the social reconstruction ideology*. In a comparative overview he brings out conceptions of aims, knowledge, learning and teaching, the learner (the child) and evaluation.

Jan van den Akker (2003) outlines some basic conceptions that are valuable when analyzing curriculum and curriculum development. First there is a differentiation between at least four levels of the education system, the system level (or *macro*), the school level (or *meso*) and the classroom level (or *micr*o) and the individual level (or *nano*). Secondly Akker empasizes the common destinction between the intended, implemented and attained curriculum:

- Intended:
    - the *ideal* curriculum: the original vision underlying a curriculum (basic philosophy, rationale or mission);

    - the *formal* curriculum: the vision elaborated in a curriculum document (with either a prescribed/obligatory or exemplary/voluntary status);
- Implemented:
    - the *perceived* curriculum: the curriculum as interpreted by its users (especially teachers);
    - the *operational* curriculum: the actual instructional process in the classroom, as guided by prevous representations (also often referred to as the curriculum-in-action or the enacted curriculum);
- Attained:
    - the *experiential* curriculum: the actual learning experiences of the students;
    - the *attained* curriculum: the resulting learning outcomes of the students.

Thirdly Akker identifies the various components of the curriculum that need attention and balancing, the first and most important one being the rationale, 'which serves as major orientation point, and the nine other components are ideally linked to that rationale and preferably also consistent with each other'. The other nine are aims and objectives, content, learning activities, teacher role, materials and resources, grouping, location, time and assessment. When considered in light of the four ideologies Schiro envisioned (see above), all these components are worthy of critical inspection. To underline the inter-consistency of the components and their vulnerability, Akker visualizes them and explains their nature as a spider web (Akker 2003).

The Science Curriculum: 'A Weed Patch of Trivia or a Carefully-Tended Garden?'

Most citizens in contemporary society presumably conceive public schools as agents that reflect and transmit knowledge, values, views, skills and wisdom that have prevailed in our culture. In science, as well as in other disciplines, an enormous body of knowledge and skills have accumulated that we do not want to be lost for future generations. But, as mentioned earlier, history has taught us that science as a school subject is dynamic in the sense that its definition and role have chronically kept changing from one time to another which inevitably has raised controversies.

Ever since it became part of the public school curriculum in Western societies more than a century ago science has undergone constant transformations (Donnelly, 2006; Atkin & Black, 2003; DeBoer, 1991), evolving from a low-status position within the curriculum, first promoting utilitarian and pedagogic purposes, which were the essence of the progressive movement, and later being defined as academic 'disciplines', with a rigorous body of knowledge and ties to university (Goodson, 1994, DeBoer, 1991). It has been influenced by different learning theories that certainly do not share common philosophies, such as behaviourism on the one hand setting clear learning goals linked to the content of the academic disciplines and objectively assessing knowledge and on the other hand constructivism requiring active participation of the learner and assessing subjectively for the benefit of the learner.

The traditional image of science education as sharing scientific content and processes with students in schools may seem incontestable and well defined, where the science curriculum normally includes physical science (physics and chemistry), life science (biology), and usually earth and space sciences alternatively. But there are constant controversies about its purpose, nature and structure (Atkin & Black, 2003; DeBoer, 1991). Such debates are steadily in progress and unity on what to teach, how, when and to whom does not seem visible at any time. Consequently the school science curriculum has become a 'crowded place':

> ...someone was always coming up with some new scientific information that everyone should know, and few people ever suggested removing anything. The result is a science curriculum that has come to resemble a weed patch of trivia and esoterica rather than a carefully-tended garden of worthwhile knowledge. While science educators agree that the science curriculum needs to be less crowded, one science educator's weed is another science educator's flower, and so nothing ever seems to get removed. In other words, there is an agreement on the general principle but, as the old saying goes, the devil is in the details (Stinner & Williams, 2003, p. 1027).

For a long time there have been strong arguments for including science as a core subject in the curriculum, but these arguments are intrinsically disparate. They imply different demands resulting in a tension between at least two main conceptions or views, on the one hand teaching science to all citizens for understanding and functioning in everyday life and on the other the needs of teaching science for future specialist jobs (Millar & Osborne, 2006). *The Twenty First Century* project, a pilot study commissioned by the English Qualifications and Curriculum Authority (QCA), is an eminent endeavor for resolving this tension between scientific literacy and science as preparation for advanced scientific studies (21st Century Science project team, 2003).

Science education for future specialist jobs calls for a discipline-based curriculum focusing on concepts and principles, while scientific literacy suggests a more general education emphasizing personal development and citizenship. With an increasing focus on science education for all citizens scientific literacy has become a major theme within the science curriculum (DeBoer, 2000; Bybee & Ben-Zvi, 2003). Although it is not a clearly defined term among science educators there is an agreement that scientific literacy implies an understanding of science for general education purposes as opposed to education for careers in science. A simple conceptualization of scientific literacy might be what the public needs to know about science, its nature, aims and ideas to be able to identify questions and problems of scientific nature confronting our society (Bybee & Ben-Zvi, 2003; DeBoer, 2000; Laugksch, 2000; OECD, 2006,).

Conclusion: 'Not fixity, but flux'

The argument here is that we live in an increasingly disordered and flexible world where stagnation does not exist. Due to conflicting visions, theories, political ideals, and other factors the science curriculum transforms over time and it varies widely at any particular point of time. Like Darwin explained with his theory of evolution, complex systems evolve from more simplistic predecessors and favorable mutations are preserved because they prove advantageous for survival and are consequently passed on to future generations. Eventually they accumulate and form completely new organisms. This study rests on this idea, i.e. that trivial changes in socio-cultural contexts, schools in our case, may trigger significant and perpetual changes if they prove beneficial for the system. Eventually the system is bound to evolve to an entirely 'new creature'. Dan Dennett (as cited in Papert, 1997) called such an evolution in socio-cultural systems a 'Darwinian design', meaning that the most important tranformations in the education system come about by evolution rather than by deliberate design.

Evolution or progress is inevitably a law of nature. But resistance to progress is practically a law of nature too. Schools and teachers have their own theories of an ideal curriculum (Meyvant Þórólfsson, Eggert Lárusson & M. Allyson Macdonald, 2009) and it is natural to resist ideas that conflict with them. The perceived curriculum as interpreted by teachers and the actual instructional process in the classroom, the operational curriculum, have a tendency of being cherished and conserved while new ideas are met with scepticism. A typical example of such resistance was the defense mechanism found in schools when resisting the influences of computers by the end of the last century. Tyack and Cuban (1995) explained this by the rigid structure of school and classroom settings. They described the nature of the classroom as a work setting and the ways in which teachers define their tasks as 'the most fundamental block to transforming schooling through machines...the regularities of institutional structure and of teacher-centered pedagogy and discipline are the result of generations of teachers' experience in ... maintaining order and seeing that students learn the standard curriculum.' (p. 124)

Maintaining the institutional structure and resisting changes does not mean that active intervention proves ineffective or void, 'but the role of the change agent becomes less like the architect or builder and more like the plant- or animal breeder whose interventions take the form of influencing processes that have their own dynamic.' (Papert, 1987, p. 418). The influence may be small in degree, even like tinkering. But transformations which prove to be beneficial for the system presumably depend on its natural needs, whether or not they have been deliberately contemplated by those concerned. With respect to science curriculum such transformations vary immensely, whether we consider them diachronically or synchronically. There are cases where the science curriculum functions as a base for further education in science, in other cases it focuses on relevant knowledge as a tool for personal and societal improvement and there are cases where the focus is on major ideas or big ideas and less on details from academic disciplines. Its functions change over time and wherever we 'take a slice through curriculum' we 'find not fixity, but flux'.

Research affirms (Bennett, 2003; John, 2005) that transactions do occur where teachers gradually reconciliate with information and communication technology (ICT) and establish new meanings and accommodations. But the process is obviously a 'Darwinian design', i.e. slow and evolutionary, highlighting that favorable modifications (mutations) survive because they prove beneficial for the system and are consequently passed on to future generations.

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‘Transformation’ of the intended science curriculum[1]

A tension between instrumental and liberal purposes

Meyvant Þórólfsson
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Reaching a consensus on the contents and purposes of the official school curriculum is not an easy task. There will always be disagreements over what knowledge is of most worth and to what extent education should promote students’ capacity to critically address societal issues. This tension has appeared to a distinct degree in science education through a competition between instrumental and liberal purposes. This paper presents results from analyzing the intended science curriculum for Icelandic compulsory schools in that respect. Sources of data are the official curriculum guides for compulsory education in effect for the last four decades of the twentieth century, issued in 1960, 1976 and 1989 and some related documents. A classification of curriculum ideologies was used as model for analyzing the data. The results indicate a constant tension between instrumental and liberal purposes of science learning. The three official curriculum guides examined in this study differ markedly with respect to ideologies that have shaped their contents.

Science as a curricular field in compulsory education

The term ‘science’ is usually not used in Icelandic, and ‘natural science’ is seldom used. In official curriculum guides and reports the term ‘nature study’ (*náttúrufræði*) is normally applied when referring to the field or subject that covers the study of living and dead natural phenomena, typically under the rubrics of biology, physics, chemistry and earth sciene. This has turned out to be problematic because traditionally ‘náttúrufræði’ has by many scholars and layman been conceived as the study of life and living things exclusively. Studying the part of nature that is insentient on the other hand has frequently been conceived as unconnected to life science, and called real subjects (*raungreinar*), real science (*raunvísindi*) or simply physics and chemistry. Natural science is an ever expanding and multiplex field with various perspectives and emphases, a mixture of different kinds of visions and educational aims, rather than a rigidly defined school subject (Donnelly, 2006).

‘Transformation’

The term ‘transformation’ is placed within quotation marks to indicate its conditional meaning. Other terms frequently used in the literature in this respect are ‘educational reform’, ‘educational change’, and ‘educational progress’. They are often used

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[1] The paper is a continuation of a paper presented at the annual Icelandic Social Science Conference, *Þjóðarspegill,* in October 2009. The first paper described the theoretical framework and rationale that underlie a study on the ‘transformation’ of the science curriculum.

interchangeably (Horn, 2002), but 'reform' usually denotes that a system supposedly needs improvement and new solutions are offered, while 'change' implies that it will be altered. Assuming that the term 'progress' means perennial growth and improvement it is important to emphasize that neither educational reform nor educational change guarantee progress of that kind.

As affirmed by Black & Atkin (1996) in their monograph about case-studies in science, mathematics and technology education for OECD, a myriad of national reports, papers and books proposing educational change in science alone have been issued in developed countries in recent decades, implying that science is indeed one of 'the most revised of established curricular areas, at least in respect of proposals for reform' as Donnelly argued (2006, p. 623).

Instrumental and liberal purposes

James Donnelly (2006) described transformation of the science curriculum as involving tensions between the 'instrumental' purpose and the 'liberal' purpose. The distinction between instrumental and liberal purposes draws on Plato's ideas of education, who argued that the difference lay in our conceptions of knowledge. According to Plato acquisition of knowledge from the liberal perspective aimed at promoting personal learning and growth, supporting each individual´s unique potential, while the acquisition of instrumental knowledge aimed at enhancing the ability to function in society, acquiring knowledge and skills as power in a societal context.

Donnelly and Jenkins (2001) portrayed the perpetual impulses for curricular changes in science education as a sort of religious correctness: 'The view that the science curriculum must change has become so common as to be an orthodoxy' (p. 2), where the above delineated tension played a central role. For the past decades the national curriculum in Iceland seems to have undergone similar changes or transformations as other Western school curricula (Allyson Macdonald, 1993, 2000) affected by similar philosophical and socio-cultural ideologies. But the waves of change usually reached the shores of Iceland some years later than in other countries. As an example, the major wave of curricular reform in science education starting in the mid-1950s and lasting until the end of the 1970s reached Iceland in the late 1960s and the next wave starting some 40 years ago, characterized by the need for an enlightened citizenry under the rubrics of scientific literacy and STS (science, technology and society), reached the shores of Iceland about 20 years later (Allyson Macdonald, 1993).

Exploring the intended curriculum

The intended curriculum is usually conceived as the official, written curriculum, issued by the authorities that shape the educational policy. Its rationale 'serves as major orientation point' (van den Akker, 2003) for other important components of the curriculum in its broadest sense, such as aims, content, learning contexts, teacher roles, learner roles and assessment. As many curriculum theorists have argued (Ellis, 2004; Kliebard, 1996; Ornstein & Behar-Horenstein 1999; Schiro, 2008; Walker & Soltis, 1997) there are various approaches to curriculum development and ways of exploring it. Herbert Kliebard (1996) and Michael S. Schiro (2008) identified four ideologies that have shaped the transformation of the school curriculum for the past century or so. Kliebard described them as humanist (or mental disciplinarian), social efficiency, developmentalist (or child study), and social meliorists. Schiro labelled them scholar academic ideology, social efficiency ideology, learner-centered ideology, and social reconstruction ideology. When exploring the intended curriculum these can be identified as follows (Table 1) according to perspectives towards knowledge, teaching, learning and assessment of learning:

Table 1. Curriculum ideologies (Donnelly, 2006; Kliebard, 1996; Schiro, 2008)

INSTRU-MENTAL **SUBJECT-TEACHER CENTERED**	**Scholar academic, Mental disciplinarian**	Knowledge as didactic statements to be transmitted. Learners seen as neophytes in a hierarchical community of the academic disciplines. Assessment as gathering objective data on student learning achievement.
	Social efficiency	Knowledge gives learners the ability to function in society, teaching involves shaping behaviour, learners are the raw material to be shaped. Assessment as means to determine acceptance or rejection (pass or fail).
LIBERAL **STUDENT CENTERED**	**Learner-centered Developmentalist**	Knowledge is personal, based on prior conditions, a derivative of each individual's learning and growth, teaching and learning as interactive exercieses, learners are self-activated makers of meaning. Assessment as means to promote learning and teaching.
	Social reconstructionist Social meliorist	Knowledge gives individuals the ability to interpret and reconstruct their society, teaching and learning seen as acculturation into an alleged good society. Learners are intelligent, social beings who´s critical thinking should be promoted. Assessment subjective, holistic.

When analyzing the science curriculum according to this classification it turns out that the scholar academic and social efficiency ideologies are strongly characterized by the 'instrumental purpose' as described above (Donnelly, 2006), i.e. generating scientifically-educated citizens by transmitting objective content that learners need to pick up and be able to recite. The learner centered and social reconstructionist ideologies on the other hand are characterized by the 'liberal purpose', focusing on students as critical human beings and enhancing their informed autonomy.

But it should be noted that such classification of curriculum ideologies represents ideals 'abstracted from reality, and not reality itself' (Schiro, 2008) implying that real rhetoric, both written and oral discourse is floating somewhere in between these extreme ideals of dynamic curricula. Meanings of concepts are also contextual. As an example, some people might assume that the scholar academic ideology conforms with the the liberal purpose of education, since it empowers studens with knowledge and skills for promoting personal growth. But according to current views on education, the scholar academic ideology is envisioned as learning and teaching the academic disciplines as prescribed by the educational authorities, which does not fit well with liberal purposes.

Method

The curriculum guides for compulsory education in Iceland, issued in 1960, 1976 and 1989 were analyzed and compared with respect to the above classification of curriculum ideologies, focusing on the field called *nature studies* (*náttúrufræði*) or *natural science* as it transformed through the last decades of the twentieth century. It is a typical text analysis where the purpose is to identify specified characteristics of the content of the official curriculum guides (Ary, Jacobs, Razavieh, & Sorensen, 2006). The phenomena being investigated are the ideologies found as bases or rationale for science learning in the Icelandic compulsory curriculum 1960–2000. The media observed are the three official curriculum guides in effect during the last four decades of the last century. Coding and analysis of data is built on the classification as described above (Table 1), i.e. what ideas emerge from each curriculum guide about *knowledge*, *learning and teaching*, *the learner* and *assessment* with respect to the ideals discussed by curriculum theorists. The texts of the curriculum guides were studied as to analyze the relationship between words and their meaning. So discourse analysis is applied in the sense that the system of relations between words and their meanings, i.e. the languge used is viewed as a social contruct.

Results

Sources of data in this part of the study are the official curriculum guides in effect from 1960 to 1999. Science covered only about 3–7 % of the whole compulsory curriculum during this period measured in pages. Broad aims on the one hand and specifically stated objectives on the other have appeared as recurring cycles which applies also to central testing. Pedagogical views, i.e. placing emphasis on learning experiences with respect to theories on learning and teaching, have also been up and down.

Tension

All the curriculum guides have had their preludes, i.e. periods of discussion about political, cultural and pedagogical emphases. Committe reports, recommendations and policy papers are usually issued in connection with the curriculum publications, shedding light on the political context of the official curriculum development. Additionally there are other sorts of data that confirm the constant tension between instrumental and liberal purposes. Among files that are being analyzed in this study are proceedings and memos about curriculum work reserved in the Ministry of Education archives.

Many such files indicate a clear tension between professional scholars in the field of science education working for the ministry and representatives of the bureaucratic authority in the ministry or even higher politically elected authority. An interesting example is a debate about the concept of 'knowledge' in a draft of the 1989 curriculum (Menntamálaráðuneytið, skjalasafn, n.d.). The bureaucrat was worried that the text was not conclusive enough about the requisition that students should acquire scientific knowledge per se in compulsory schools: 'The compulsory school (*grunnskólinn*) is certainly not only a preparation for the secondary school ... It has its independent goals, among other things regarding students knowledge'. The scholar maintained on the other hand that the compulsory school should emphasise enquiry learning, where the students ought to encounter natural phenomena, and discover their nature: 'It fascinates many students more to acquire knowledge through challenging means from original sources, and by observing and experimenting rather than assimilating solely what others have acquired and put into books'.

1960

The 1960 curriculum, labelled *Námskrá fyrir nemendur á fræðsluskyldualdri* (*A curriculum for students on the age of compulsory schooling*), was in effect for 16 years from 1960 to 1976. It was built on the Educational Act from 1946, having been written as draft in 1948, but not finally published until 12 years later. According to the introductory chapter the prescribed curriculum has an exemplary or voluntary status, 'its role is first and foremost to guide teachers and administrators about organization and selecting learning contents' where teachers and adminstrators 'make sure that each student gets proper assignments according to his or her capability' (Menntamálaráðuneytið, 1960, p. 5). The curriculum was published in one book divided into chapters according to the names of the school subjects to be taught. Each subject chapter was then divided according to the age of students from 7 to 15 and what was to be taught and learnt in each grade.

The chapter on nature study covered pages 41–46 starting with a few lines about general aims concerning 'nature study instruction' which 'is supposed to help students acquire knowledge about the predominant phenomena of nature, focusing on what they need to know about with respect to daily life' (p. 41). Then there are subchapters that resemble a sort of catalogue about what should be taught and learnt:

> Example 1:
> Icelandic mammals and birds: Instruction should focus on body characteristics, body structures, offspring ... Learning should focus on knowing the main characteristics of mammals and birds (p. 41).
>
> Example 2:
> Chemistry: Chemicals, compounds, elements, molecules and atoms. Elements of the atmosphere. Combustion, corrosion, water. Distillation. Elements of water. Alkali, acid and acetates (p. 44).

At the end of each subject chapter in the curriculum there was a subchapter called 'For further reviewing' (*Til athugunar*), with some interesting recommendations about the process of learning and teaching. In the subject chapter about natural science the curriculum authors argue about the importance of relating new knowledge to prior learning, using the natural environment of the school as subject matter, appreciation of nature and wildlife conservation. And finally there are suggestions about hands-on learning, that students discuss and present their work orally and in writing. Making workbooks in natural science is considered important.

According to the above analysis, the 1960 curriculum is primarily characterized by the instrumental purpose, it is subject–teacher centered. Knowledge is to be transmitted, providing learners with the ability to function in society. Teaching involves shaping behaviour, where learners are the raw material to be shaped. Although there are no clauses about assessment specifically, the structure of the curriculum is in favour of the view that assessment involves gathering objective data about the achievement of learning.

But the 1960 curriculum is not solely under the influence of mental disciplinarian and social efficiency ideologies. As the subchapter 'For further reviewing' indicates, pedagogic theories of child development and consequently the liberal purpose of education is certainly taken into consideration. There are even signs of social constructivist methods of learning.

1976

The 1976 curriculum (Menntamálaráðuneytið, skólarannsóknadeild, 1976) was issued in 10 booklets under the rubric of *Aðalnámskrá grunnskóla* (*The national curriculum for compulsory schools*). It was in effect for 13 years from 1976 to 1989, built on the Educational Act from 1974. Natural science was divided into physics including chemistry and biology. Learning materials and all discourse about science aimed at dissociating these two facets of natural science, physics-chemistry on the one hand and biology on the other hand. The physics-chemistry curriculum was issued in September 1976, but the biology part was never completed. Two officially appointed committees on science education, one on physics-chemistry, the other on biology, published reports with recommendations about the reform of natural science in Iceland. The reports were under the influence of the major curricular reform originated in Western education in the mid 1950s and the direction was conclusive:

> … the main purpose of physics and chemistry instruction in lower-secondary schools is to prepair students for living and working in a changing society so that the ordinary citizen will neither be frightened by science nor worship it in blindness. He should realize that the cause of most natural phenomena is normal and that the application of scientific working methods is important in order to understand and have some control of our environment (Menntamálaráðuneytið, 1968, p. 8).

The booklet on physics-chemistry covered 15 pages, starting with general aims stressing knowledge and understanding of essential topics in physics and chemistry, practicing measurement and systematic observations, focusing on applying knowledge to resolve new problems, interpreting results from observations and discussing results. Then there are statements of what students in lower-secondary schools are expected to know and be able to do upon completion of learning physics and chemistry. It was classified into seven categories: Measurements of time and distance, properties of matter, compounds and the atom theory, thermodynamics, mechanics, wave theory and electronics. The last chapter in the curriculum booklet is labelled 'instruction methods', suggesting that students work in groups when solving problems and doing experiments. It is considered important that students compare their results and discuss variations in outcomes.

According to the above analysis, the 1976 curriculum was characterized by the instrumental purpose as was the 1960 curriculum, actually with a more rigorous body of knowledge and ties to further academic science learning. Students need to acquire a great deal of scientific knowledge and skills although the 1976 curriculum does not adhere the teacher-as-transmitter-of-knowledge model of science education. Learners are conceived as neophytes in a hierarchical community of the academic disciplines, but their learning should resemble the work of the scientist: 'The difference is in degree, not in kind. The schoolboy learning physics is a physicist, and it is easier for him to learn physics behaving like a physicist than doing something else' (Bruner, 1966, p. 14). Teaching involves shaping behaviour, where learners are the raw material to be shaped. Although there are no clauses about assessment specifically, the structure of the curriculum is in favour of the view that assessment involves gathering objective data about the achievement of learning. Assessment is considered as means to confirm achievement of learning, informing the student and his or her parents, authorities and schools on the next school stage about achivements of learning.

Although the 1976 curriculum suggested group work and enquiry learning or discovery learning, altogether it features an instrumental, subject-oriented model of learning.

1989

The 1989 curriculum was issued in one book where the science part covered 10 pages of 196 (5%). The title was the same as in 1976, *Aðalnámskrá grunnskóla* (*The national curriculum for compulsory schools*). It was in effect for 10 years from 1989 to 1999, built on the Educational Acts from 1974, 1991 and 1995. The first part of the book covered general aims for compulsory schools, and chapters about the role of compulsory education, about schools as institutions of a developing society, about theories of child development, learning environments and the integration of school subjects: 'Systematic integration of two or more school subjects incurs that subject matters are examined from different perspectives and should thereby provide a deeper understanding and a more holistic view ... Thematic learning applies knowledge and methods from different school subjects, and thereby the boundaries between subjects are blotted out' (Menntamálaráðuneytið, 1989, p. 32).

The second part of the curriculum was divided into chapters according to the names of the school subjects to be taught in alphabetic order. The chapter on nature study, labelled *Nature study (physics, chemistry and biology)* (i. *Náttúrufræði (eðlis-, efna- og líffræði)*) started with a general discussion about nature study as a school subject, including a philosophic discussion about the role and nature of science, its connection with daily life and other educational disciplines. Then there is a short passage on the main goals, where the main focus is on 'sympathy towards life, nature and the environment ... critical attitudes towards nature conservation ... inquiry learning ... working together with other students on science projects ... exploring big ideas and whole contexts in nature and finally: ' know and understand basic theories in physics, chemistry and biology and the impact of those sciences on our way of living and our world view.

According to the above analysis, the 1989 curriculum was characterized by the liberal purpose rather than the instrumental purpose and the social meliorist perspective was not far off, because of the tendency to urge critical thinking and see teaching and learning as acculturation into an environmental friendly society: 'Natural science and technology are among the most important preconditions for our way of living, but also what endangers our future most of all' (Menntamálaráðuneytið, 1989, p. 106).

Although the 1989 curriculum specifies the acquisition of scientific knowledge and skills to a certain extent the goals and objectives are too open-ended and ambiguos to be understood as instrumental or subject oriented, and can not at all be interpreted as scholar academic or mental disciplinarian. On the other hand there are many interesting recommendations about the process of learning and teaching, using group discussion, relating to students' own experiences and prior ideas, using the natural environment of the school as subject matter, and practicing hands-on learning through direct contact with natural phenomena.

Discussion

The first issue of concern that needs further discussion is the limited space natural science has in the official curriculum, no matter whether it is characterized by the liberal or the instrumental purpose. As argued before, science is an expanding field in the whole curriculum, a mixture of different kinds of visions and educational aims, rather than a rigidly defined school subject. An OECD report about the Icelandic education system (OECD, 1987) affirmed that Icelandic curricula differed markedly in the balance of subject areas from what was common in other countries: 'The crux of this difference is in the large amount of time devoted to language learning, both of the mother tongue and of two foreign languages, which of course limits other areas such as social studies, history beyond Icelandic history, and science' (OECD, 1987, p. 23).

Conceiving natural science as an expanding field with limited space in the compulsory curriculum we need to pay attention to what Elliot Eisner termed the 'null curriculum' (1985), i.e. the elements that we are forced to decide not to teach, thereby giving students the notion that these elements are not important. They inevitably get the message that the content or processes involved are not significant enough to be included. Ignoring such elements 'is not simply a neutral void; it has important effects on the kinds of options one is able to consider, the alternatives that one can examine, and the perspectives from which one can view a situation or problems' (Eisner, 1985, p. 97).

Another facet of this very problem is an overcrowded curriculum. Stinner and Williams (2003) phrased this situation as the school science curriculum becoming an ever more 'crowded place', appearing alternately as 'a carefully-tended garden' to some people, and 'a weed patch of trivia' to others: '...someone was always coming up with some new scientific information that everyone should know, and few people ever suggested removing anything'. If perpetual impulses for curricular changes in science education have become so common 'as to be an orthodoxy' as Donnelly and Jenkins (2001) described it, then the transformation of the science curriculum over time may appear as recurring cycles of ideals. This little study certainly indicates that ideologies such as the scholar academic, the social efficiency, the learner-centered and the social reconstructionist do seem to appear as recurring cycles.

But we must bear in mind that changes within the culture of education such as the transformation of the science curriculum do not take place in a vacuum. We need to take into account external factors that affect curriculum transformation, i.e. technological, economic and social structures, which inevitably 'set parameters and possibilities for internal change' (Goodson, 2005). So progress does happen, 'we can not step into the same river twice'.

Finally it should be emphasized that when the curriculum in natural science is viewed from an international perspective, it has evolved with respect to the above delineated ideologies in its own particular manner, featuring the teacher-as-transmitter-of-knowledge model as in the 1960 curriculum, discovery learning model related to abstract scientific concepts and viewing the pupil as a scientist as in the 1976 curriculum, and finally a sort of socio-cultural model, focusing on the integration of science with other subjects, societal issues and environmental issues as in the 1989 curriculum. Other focal points in the history of science education, such as scientific literacy, social constructivist learning, STS (science-technology-society) and ESD (education for sustainable development), were certainly not far off in the official curricula in 1960, 1976 and 1989 though they had not yet been brought up literally in the curriculum texts before the end of the twentieth century.

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APPENDIX II

Five Science Teachers

Articles IV and V – Five Science Teachers

The second category of data was based on qualitative sources. Five science teachers' professional ideas about science education were solicited through individual interviews and their classroom practices were observed as a precursor to short follow-up interviews. Data collection took place in 2005.

The findings illustrated their practices and ideas with respect to the 1999 national curriculum (MESC, 1999a), which comprised three main perspectives: First, much clearer and more precise objectives than ever before and the readoption of centralized national examinations; second, constructivist ideas on learning and teaching; and third the application of ICT in science education. *The Five Teacher Study* indicated a complexity of school cultures, although all participants experienced the pressure for curriculum coverage as a constraint on their decision making while simultaneously trying to meet their students' different needs and diverse learning styles.

Table 1. Profiles of participants in *The Five Teacher Study*. Pseudonyms used.

Icel. pseudonym	JAKOB	ÓLÍNA	AÐALSTEINN	SAGA	SÍMON
Engl. pseudonym	JACOB	LIN	PETER	SAGE	SIMON
Gender	Male	Female	Male	Female	Male
Interview 2005	Feb 9th	March 8th	March 10th	March 15th	Oct 30th
Observation 2005	March 5th	May 12th	Nov 9th	April 7th	Nov 7th
Teaching experience	9 years	3 years	6 years	36 years	15 years
School Type	Gr. 8 - 10	Gr. 1 - 9	Gr. 1 - 10	Gr. 1 - 10	Gr. 1 - 10
Education	B.Ed. Science	B.Ed. Science	B.Ed. science	Teacher certificate	B.Ed mathematics and technology
Other education	Dental mech.		Engin. & ICT		ICT

Article IV: ***Five public school teachers' conceptions about science learning and teaching*** **[i. Sýn fimm grunnskólakennara á nám og kennslu í náttúruvísindum]**
Þórólfsson, M., Macdonald, M. A., & Lárusson, E.
Journal of Educational Research (i. *Tímarit um menntarannsóknir*) 2007, 4, 83–99

Article V: ***Learning science with ICT*** **[i. Náttúrufræðinám með stuðningi upplýsinga- og samskiptatækni]**
Þórólfsson, M., Macdonald, M. A., & Lárusson, E.
the Journal of Educational Research (i. *Tímarit um menntarannsóknir*), 2009, 6, 85–106

The Views of Five Teachers in Compulsory Schools on the Learning and Teaching in Science[1]

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In the last few years guidance on teaching has been more visible for science teachers. In particular, this has come through the national curriculum in 1999 and the introduction of national exams in 2002. In the school, teachers' still have to meet the varied needs of a diverse group of pupils. In 2005, the view of five science teachers was solicited through analysis of interviews and field observations. The main purpose was to see how they connected the specialist knowledge and professionalism to meet the needs and different pre-condition of a diverse group of students at the same time as they met the obligations contained in the guidance provided in the national curriculum. The results indicate that stress is created in trying to meet both these conditions, that are the guidance from the outside on the one hand, and the real demands in the classroom on the other. The discourse of the teachers interviewed focuses largely on the latter but how they organise the learning and teaching seems to reflect more the former. Covering of study materials seems to be emphasised more now than before but flexibility and time for practical work seems to be correspondingly less.

Practical application: The authors feel that there is a reason to consider the work conditions of teachers following an increased emphasis on science in compulsory schools after the implementation of the 1999 national curriculum, national examinations in science and participation in PISA 1996. Tension or stress among teachers seems to have come with these changes. Light is thrown on the professionalism of teachers who are experts in upbringing and education on the one hand and in teaching of subjects like science on the other. The article should be useful for researchers, policy makers, teachers and teacher-education institutions to map the effects of increased emphasis on the study of science on learning and teaching in compulsory schools.

It is in fact taken for granted that teachers have some guidance from above which governs to some extent what they teach at any given time – how and why. Among compulsory school teachers the national curriculum in science and environmental education (1999, 2007) are examples of such guidance. However, teachers read the official curriculum and interpret it using different glasses; some read it well and follow it diligently: "I even have it on my bedside table" one teacher said. Others say they can hardly remember what the curriculum booklets look like. The same can be said about the study material in national exams and other written material which teachers and students get. Such texts and materials certainly influence learning and ways of teaching but in different ways and to a different extent.

[1] Originally published in Icelandic in Tímarit um menntarannsóknir (Journal of Educational Research), Reykjavík, Vol. 4 2007, p. 83–99. http://fum.is/wp-content/uploads/2010/09/5_meyvant_allyson_eggert1.pdf.

Icelandic title: Sýn fimm grunnskólakennara á nám og kennslu í náttúruvísindum. Tanslated from Icelandic by Marín Rós Tumadóttir.

The main goal of this study was to explore the ideas science teachers have on the study and circumstances of students and what type of professionalism characterised their work after the implementation of the national curriculum for compulsory schools in 1999, in particular how they connected their knowledge and attitudes to take into account the manifold preconditions of a diverse body of students at the same time as they seek to meet obligations expressed in the guidelines from above. It should be pointed out that Rúnar Sigþórsson (2007) is now studying the effects of national examinations in science and Icelandic on the work culture of teachers and pupils in Icelandic schools where he highlights the influence of evaluation, not least national examinations, where all actors have considerable vested interests. Here we look at the guidelines from above in a wider context, in particular how they are expressed in the national curriculum.

The curriculum and the teacher

Goals in studies of science to a large extent focus on the fact that pupils should realise the influence of science and technology on their environment, lifestyle and community at the same time that they get trained in practical skills in carrying out observations, searching for explanations and solutions, and the evaluation and presentation of results. (National curriculum in compulsory schools. Science and environmental studies, 2007). The science teacher must therefore be well versed in the special philosophy and methodology that characterises science. He has to know scientific methods and the demand that the study of science has a connection to social issues and calls for training in deduction and critical discussion.

According to Shulman (1989, p.9) subject teachers should possess at least three types of specialist knowledge in addition to general pedagogical knowledge. Firstly, it relates to the subject matter content knowledge, its characteristics and logic. Secondly, it is pedagogical content knowledge (PCK) that is the knowledge of appropriate methods and ways to organise studies and teaching in the subject, which is to introduce pupils to its concepts, methods and ideas. Such knowledge has also been termed more subject specific pedagogy (cf. Lederman, 2001; Soares and Lock, 2007). It is worth noting that PCK has received increased attention in teacher education and research into teacher education; it is recommended that training of teachers include an integration of the subject and its pedagogy; for instance it is not desirable to teach chemistry in the first lesson and pedagogy in the second. Finally, Shulman considers curriculum knowledge, which is the study materials and information and also the overall context and organisation of school work. In addition one must not forget the importance of knowledge of the pupils themselves, their diversity and the social context they are a part of. (Bransford, Darling-Hammond and LePage, 2005).

When the national curriculum from 1999 took effect, science subjects received more attention than before and are now allocated 9-10% of fixed hours in the reference timetable for compulsory schools. There were more goals, aims and objectives divided into several objectives, for all levels of compulsory schools and the content became more wide-ranging; in addition a national final exam in science was started again in 2002 after a break of almost two decades. The goals of science in compulsory schools were broken into main three categories. Firstly, there were goals on the role and nature of science with a particular emphasis on the influence of science on the lifestyles and attitudes of modern man, his environment and society. Secondly, there were goals about the methods and skills of science where it was expected that pupils received training in how to carry out observations, search for explanations and solutions, and evaluate the results. Finally, there were content goals which were divided into physical, earth and life sciences as it is phrased in the curriculum.

The scope of science is broad and therefore it is not easy to prioritise or make an order of priority about the content which is considered necessary in the aim of education for all. Concepts and topics from physics, chemistry, world science, earth science and biology are selected and presented with regard to their importance within each area and interconnection but also not least how they relate to the environment of compulsory school pupils and the environment they experience in the present and the future. Here it can be added that according to the regulation on the registration of students in secondary schools (nr.98/2000) pupils must get a minimum grade of 5.0 in the national examination in science to be able to get into the so-called science tracks in secondary schools.

In spite of clear aims, goals and objectives in the curriculum it is by no means self-evident what should be taught, to whom or when. This applies in particular to science. According to an analysis by Kliebard (1987) this is influenced by certain new ways of thinking which are based on peoples' ideas on the societal and political role of schools, the study of knowledge, maturity to learn and social development. Two main ideologies have for some time been more apparent than others in this regard (see e.g. Labaree, 2005, Parkay, 2006). On the one hand there is what Parkay calls the subject-centered curriculum which is characterised by clear goals, efficiency, objective evaluation and the written subject curriculum, where the teacher and the school book have the greatest influence on the process of education. On the other hand there is the student-centered curriculum which takes into consideration different needs, ideologies and situations of pupils and does in fact not assume that work in schools can be governed by written plans in all aspects. In this context, John Dewey spoke on the one hand about traditional education and on the other hand about progressive education and considered to what extent experience, pre-conceived ideas, and the individual needs of pupils were important in the planning of learning and teaching for instance in science (1938, p.17). One of the most interesting examples of these sorts of ideas in Iceland appeared in so-called work-skill studies which had a great influence on the work in Icelandic schools from the mid 1980's into the mid 1990's (Sigurðsson, 1991).

Elliot Eisner (1990) put it thus when he discussed the influence of guidance from above: "...good curriculum materials both emancipate and educate teachers" (p.65). The flexibility teachers need in their jobs as professionals is certainly connected to the necessity to plan learning and teaching in a diverse way in line with the goals of the curriculum, but it also contains ethical issues, for instance, to consider different needs and special conditions of their charges "...ethical thinking and decision making are not just following the rules" (see Strike and Soltis, 1985/2004).

Eisner (1990) also pointed out certain problems for experts outside schools that wrote curricula and study materials, that is, their distance from the classroom and therefore the problems associated with trying to put forward some sort of recipe of what should take place without knowledge of and paying regard to the multiplicity of conditions and contexts. Thus texts in curriculums can lack meaning to teachers and pupils or be seen as "a hodgepodge of ideas", see the descriptions of Þórbergur Þórðarson (1986) on how to read and try to understand unfamiliar texts. During the last decades people have increasingly sought ways to bridge the gap because it is unrealistic to make a standard prescription on what happens or will happen in the daily schoolwork in the ever-changing and unexpected interactions and work of pupils and teachers (Eisner, 1990; Sarason, 1982; Schwab, 1969).

Teachers must make a lot of effort to keep up with current knowledge in their area and how best to use it in general schoolwork and for obvious reasons it is a short term solution to try to define content and goals in subjects like science as a "ready made" or final package of knowledge which can be transmitted or introduced to pupils in a traditional way (C.F. DeBoer, 1991, p.222).

Decision making and professionalism

The so-called seven frame model reflects the issues teachers have to make decisions on in organising lesson (figure 1). The idea was developed and based on the analysis Hewson and Hewson from 1988 on learning and teaching (Macdonald, 2002). The main argument presented in the model is that when we organise school work and consider how best to teach we usually look at the materials, goals, teaching methods and evaluation or the clear boxes. The teacher and the managers of school thus refer to the guidance from above discussed earlier and then set goals for the pupils accordingly, select materials, plan teaching activities and decide how to evaluate in line with traditional education, as Dewey calls it.

Each and every pupil comes to school with his or her own ideas based on experience and pre-conceived ideas about what he or she is going to learn. Pupils also have their own styles and needs when it comes to studies and their experience of studies and results is as varied and unpredictable as they are many. If results are to be obtained we cannot avoid paying particular attention to the pupils themselves (the grey boxes), their starting point, experience, study activities and assignments. How well they do in their studies depends on the initial state of each pupil and activities and the evaluation methods and tools usually used in schoolwork do not make it possible to evaluate the pupil except to a limited degree.

The professional (science teacher) has to be well-informed on the condition of the pupils if the results are to be obtained. The teacher also needs to be knowledgeable about the goals and content of the subject. And to be a professional, the teacher also needs to keep up with the rapid development of knowledge within science and technology. Not only is the reality moving at a fast pace, changing all the time, but also the nature of our knowledge on it and our understanding of it as Thomas Kuhn explained in *The Structure of Scientific Revolutions* (1996). He found it necessary to point out that scientists had the same characteristics or weaknesses as other people and they differed and depended on their experiences and environmental conditions in their lives. The creation of scientific knowledge is therefore in reality relative and ever changing rather than absolute and final.

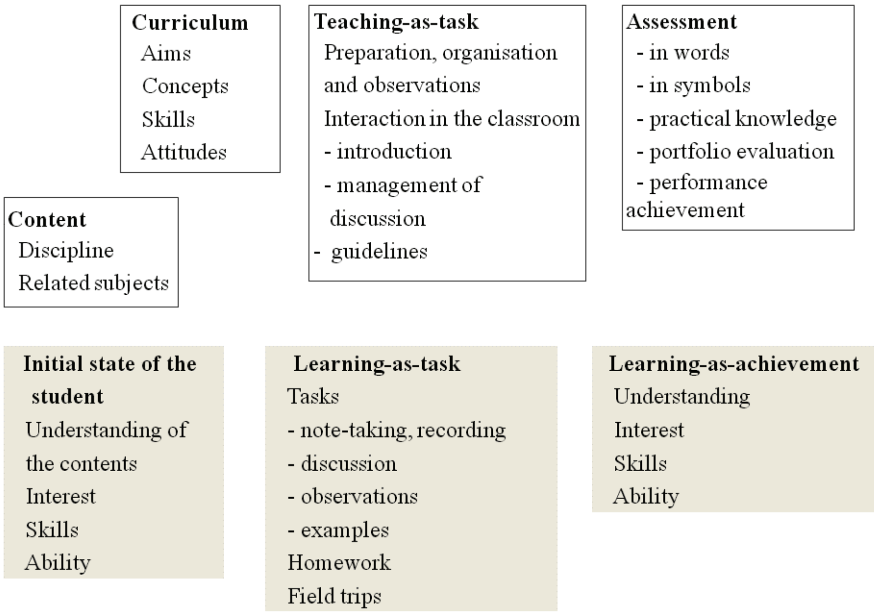

Figure 1. When we organise teaching we usually look at the materials, goals, teaching methods and evaluation as presented in the clear boxes. If results are to be obtained we need to pay attention to the pupils themselves (the grey boxes), their starting point, experience, study activities and assignments.

Teaching in science is a specialised job which calls for specialised knowledge and professionalism. Therefore it is reasonable that teachers in this area claim monopoly on their work and support that claim by their education, their experience and academic degrees. The professionalism of those who engage in science education is not only about knowledge of concepts and ideas which are to be transferred to pupils but also the ability to analyse changing circumstances and select methods, tools, information and study conditions that are appropriate at each time. The professional is primarily committed to do what he or she thinks is best for the pupils (Þorsteinsson, 2002, p.189), but he/she also has to consider other interests.

Many different interests are reflected in the decisions of compulsory school teachers, as they are responsible in taking part in formulating policies and making plans and curricula which influence the life and work of all members of society for ten years of their lives. Such decisions are not only reflected in the selection of study materials and study situations but are also social, emotional, philosophical and political issues (cf. Stryke and Soltis, 1985, p.95). Considering this we must regard teaching not only as a technical work but also as an ethical process (cf. Macdonald, 2000). This is also emphasised by Noddings (1993) in his discussions on the ethics of caring. Noddings says that teachers need to have a holistic view of their pupils development and give all things equal consideration, that is the mental maturity and ethical and social maturity of pupils. In other words, the obligation the teacher has towards the job and what it entails, and even to a greater extent their charges, their pupils.

Many have discussed the professionalism of teachers and seem to draw up the following main characteristics. Professionals feel that service is more important than financial benefit, the discipline requires specialist knowledge and long specialist training which is based on well-formulated theories, individual members and the group of professionals as a whole have considerable freedom to exercise independent decision making, members or a group of professionals have similar values that often appear in ethical guidelines, they have responsibilities and obligations *vis-a-vis* their clients and their work environment, they guarantee the professional conduct and capacity of each other, they have a certain degree of authority and influence over their clients and the nature of the service makes it impossible for those receiving it to evaluate it (Macdonald, 2000; Furlong et. al. 2000; Rich, 1984).

Trausti Þorsteinsson (2003) points out that there are at least three types of teachers as professionals and refers to the writings of Peter Ribbins from 1990 and Andy Hargreaves from 2000. Firstly, it can be the case of the ‘dependent professional’ who primarily follows the instructions of an authority figure and sees his or her main obligations to follow the instructions of the authorities and that above all else they have responsibilities and obligations towards the plans and rules set by them, the professionalism is expressed by knowing the official policy, interpreting it and following it. Secondly, there is the ‘independent professional’, the one who allows himself to deviate to some extent from what is prescribed by the authorities and rather looks at the needs of pupils, the environment of the studies and the social context for learning and teaching but at the same time is mainly bounded by himself and his pupils. Finally Trausti mentions the ‘collaborative professional’ who conforms to the ideas of team work and to see the work of the school in a holistic way, where co-operation and collaboration are of primary importance. On closer inspection one can detect a resonance between the ideas of Trausti and Furlong et.al, with the three categories of Shulman described above. The ‘dependent professional’ primarily looks at the goals and the content of what is being taught. The ‘independent professional’ evaluates situations, uses methods and organisation based on that and uses plans in accordance, while the ‘collaborative professional’ thinks about the school work in a wider context and considers his or her role as sharing with others in the overall context.

The research questions

The research question considers two main issues, on one hand the ideas of five science teachers about learning and teaching and on the other hand the nature of professional consciousness and to what extent science as a subject is special in this context. In the results an attempt is made to answer the following main questions :

- *To what extent do the five teachers consider the different situation, action and results of pupils (the dark squares in the seven frame model) when they plan learning and teaching according to the guidelines from above?*

- *How is professionalism and professional consciousness expressed by the respondents in this research and what the special position of science is in that regard, c.f. issues highlighted by Shuman et. al. about professional knowledge, teaching of subjects and general knowledge of pedagogy?*

Five teachers were interviewed, three women and two men, who are working or have worked as science teachers in upper levels in compulsory schools and their teaching was also observed. Interviewees were consciously selected; it was known that they had the specialised knowledge of a science teacher and some experience of science teaching. The first interviewee was chosen because he is well known for his interesting organisation and study of teaching, has specialist training in the teaching of science and his pupils have had good results in the national examinations. He identified the next two interviewees as interesting teachers and finally two more were selected based on gender, education and broad experience of teaching as the researchers knew of them as serious and progressive teachers of science. Four of them taught in the upper classes of compulsory schools with some experience of the intermediate level. The study commenced in February 2005 with the collection of information. Semi-structured interviews of approximately 60 minutes each were taken. The components of the teaching model discussed earlier (figure 1) formed the basic frame for the questions. Every teacher was initially asked to describe a typical lesson which he/she had thought to be successful. In this way we sought to get at the beginning of the interview the view each interviewee had on what constituted a good lesson. The questions covered home assignments and national exams and towards the end the use of IT in science teaching was discussed. The goal was to obtain a holistic view of the conditions of each of the five teachers.

Every interview was followed by the observation of one lesson in the classroom of the teacher in question and the recording of the activities. At the end of each field study important issues were discussed with each teacher and further questions asked which were raised by the first interview and the field study.

The interviews all took place in the classrooms of the teachers. They were taped, transcribed and analysed. The analysis was based on qualitative methodology where phenomena were interpreted based on the meaning people attributed to them. The interpretive approach is a method to interpret text and obtain a valid or just meaning of it (c.f. Kvale, 1996), an attempt is made to identify important interpretations in the data, test them and review them as need dictates. Kvale thus talks about interpretive analysis as a hermeneutical circle which could theoretically continue infinitively (p. 47).

Results

In the results we attempt to elicit how the five teachers react to a multi-facetted situation, both the activities and results of pupils (c.f. darkened boxes in the seven frame model) when they organise learning and teaching. Secondly we discuss the specialist knowledge and skills which are of use to teachers of science, see Schulman and others, and the necessary knowledge and views of subject teacher and at the same time the nature of the professional self-consciousness of the interviewees. Code-names are used when referring to quotes or activities of interviewees.

Organisation of learning and teaching (cf. seven frame model)

At the time of the study Sage taught physics in the 6th to 10th grade, but prior to that had taught Icelandic and maths in lower secondary for many years. About 10 years ago she took extra studies in physics and chemistry. She says that pupils learn best by carrying out experiments themselves but „unfortunately the national examinations mean that they cannot do their experiments, especially because we went on strike... we have to cover all the material, that comes first". When asked if she listens for the ideas of pupils and asks them questions about their views and experiences she answers in the negative and says she is not comfortable with such teaching methods.

Peter taught physics and maths at the lower secondary at the time of the study. He plans his teaching carefully well in advance and gives his pupils an itemised plan for the whole term. All pupils cover the same material in physics at the same time and the same speed whether they intend to sit the national examinations or not. In a typical lesson Peter starts by noting who has completed their homework, then he discusses the topic of the day and gives short presentations, as he puts it, carries perhaps out a demonstration experiment or a short practical exercise which he carries out himself; he says he does not make the pupils carry out experiments themselves because it is of little use. In the lesson we observed Peter presented the transfer of heat in the ninth grade. The pupils seemed quite interested and there were some interesting discussions. But it emerged both from the interview with him and also from the observations that what matters are his teaching activities (the clear boxes in the model), but to a less extent the learning activities of pupils (shaded boxes).

Lin said that she didn‘t see herself as a leader or a preacher, that would encourage rote learning, but rather some sort of a manager that provided tools and equipment and the right conditions. During the field observation, Lin’s pupils who were in the 7th grade made a project about birds which were on posters. The project involved drawing, cutting and gluing pictures of birds, preparing a map of their migrations or writing a text based on printed information off the web of the Institute for Nature Studies. Even if pupils had considerable lea-way and independence in this lesson their motivations did not seem strong. Published material and exams based on those carry considerable weight with Lin. In one place she says: “It is so convenient if you have a book and teachers guide and everything has been decided for you that you are supposed to do”. In another place she talks about the need for “introducing new concepts... and then there also have be definitions and other things which only come under direct teaching”. One can infer from Lin’s answers that the pupil centered curriculum is important to her (shaded boxes). But her actions and organisation indicate that the subject or teacher centered curriculum is at least not too far away.

Jacob who taught physics and biology in lower secondary at the time of the study is clearly closer to conduct and organise learning and teaching that reflect the ideas of the variability among pupils, their differences and experiences. He appeared adapt at capturing the minds of his pupils in interesting conversations for instance by connecting to material from the magazine Living Science. When asked about discussions outside the subject he replied that he would without hesitation use such discussion to further learning if possible and “...let it role...such lessons are very valuable when everybody is interested because it comes from them. I would never stop it because one could build on it”. The researchers had the opportunity to observe such a discussion with him about the atmosphere of the earth and things related to the atmosphere of the earth such as greenhouse effects, the ozone layer, the effect of ultra-violet light, freon, fuel supplies of the earth, electro-magnetic fields and many other things. In the discussion the pupils brought up some interesting questions and ideas. Jacob asked one of the pupils if he could explain what greenhouse effects were. The pupil said he could do it if he was allowed to come up to the blackboard and draw it, but that did not happen, another pupil was allowed to answer, and together they answered the questions, he and the teacher.

Even if Jacob takes into account the situation of the pupils (cf. the shaded boxes) nobody can be left in any doubt that the goals in the national curriculum and national exams have a considerable affect on his daily work and that of his pupils: “the national curriculum is the main thread, at least in the science studies with me...we also respect the studies and the exams... they know they don’t get away with any nonsense and not reading, my goals are reasonably clear and I test them and they know what they are”.

Simon taught maths, physics and technology in upper primary and lower secondary at the time of the study. He thinks it is important to continuously be aware of the interests of the pupils and to use the interests of the pupils to spark off work and projects within the school. He says he often deviates from the planned organization to “take some detours” as he calls it. As an example he says that the “naughty boys” had shown an interest in an ancient weapon, a sling shot, and thus this weapon became the subject both in maths and physics, amongst others, in modelling. Simon expresses his concerns repeatedly that the school system does not take into account the different capabilities of the pupils. That is most evident in the emphasis on rode learning in the national exams. When Simon is asked about his self-image as a teacher he says he is somebody who thinks and discusses with pupils. “...if you start speculating with them, then somehow the flow changes. But if you are like you know it all... they have to experience you see the process on their own premises, otherwise the understanding will not follow”. Here it is clear what sort of teaching activities Simon prefers.

But he says that in spite of this he has to read carefully the curriculum and study materials and try to cover all the main content as there is now a national exam in science which 70% of his students register for. Guidance provided by the curriculum and the exam is however a concern to him as it does not rhyme with the philosophy he seems to favour. In one place he talks about a pupil who possibly “excels at mathematics and spelling and English and Danish and all these subjects and can learn it all by heart and can express it all reasonably coherently but his practical skills seem to be non-existent. The child in question can hardly keep himself clean and can hardly do his own cooking and possibly not change a light bulb without calling an electrician”. He is therefore also thinking about the moral and social maturity as well as the intellectual maturity, cf. Nodding’s ideas on ethics of caring mentioned earlier.

Among the five teachers, a similar picture emerges as Labaree (2005) and others (e.g. Goodlad, 1984, Zilversmit, 1993) have painted of schoolwork and the development of schoolwork where the discourse itself centres to a considerable extent on the interests of pupils, their needs, diversity and conditions, but when it comes to implementation the organisation of the studies and lessons, such consideration is not as apparent as one might expect. Instead, the efficient curriculum policy becomes more visible as the curriculum, study books and exams are in the forefront. The five teachers in this study turned out to be quite different in this respect. Almost all indicated in some way that it was unavoidable to take into account the situation of pupils when planning the teaching of science.

Decision making and professionalism

Sage has attended courses in continuing education in physics purposefully and she says that she has a reasonably good command of the main topics. Her main strength seems therefore to be the demand and content of the subject and its characteristics. But she feels at a disadvantage when it comes to teaching methods and also the selection of information and equipment for teaching. She says for instance that she is not good at asking questions and keeping up discussions about the content she is teaching: “There is not much discussion... that is something one has to learn and I‘m not good at it. There is no structure to it”. There are however examples of interesting teaching methods in her lessons, for instance what she calls “a play” which is in effect interesting demonstrations and experiments with discussions. In the lessons we observed it aroused our interest that she took the whole class with her into the stairwell of a block of flats and carried out an experiment about forces, energy and movement. Sage says that she often sees an urgent need to help students connect and understand and takes an example about temperature and the freezing point, all students have for instance experienced when water freezes for instance but their ability to read off a thermometer is unbelievably weak. She said she lacks ideas or methods and she has for instance not mastered the skills to make use of the internet and or called for support from colleges. “...one is like an island, when you don‘t get any ideas from anywhere else”. According to the categories of Trausti Þorsteinsson, dependent professionalism applies when the professional is dependent on external conditions and prescriptions and tries to fulfil them (p.192) but avoids making independent evaluations and to “determine the needs of pupils and how they can be met” (p.195). Sage falls primarily into this category. She tries to master good knowledge in the subject which she teaches; she sees herself rather as a transmitter of knowledge rather than a plain pedagogue and values her independence as an expert in the classroom.

Peter also has a reasonably good command of the content knowledge, however to a rather limited degree. When asked if he considers himself as having a strong background in his subjects, physics and maths: “Yes, compared to others, I think I am ok.” His professionalism falls into the same category as Sage’s. He considers his roles primarily as the transmitter of knowledge and evaluates results using traditional methods, rather than being concerned about the individual characteristics of each pupil, pedagogical issues or problems associated with learning. Peter comes nowhere near of falling into the category of being a collaborative professional according to Trausti. He says for instance that he does not know the teaching plans of other teachers and he is not sure if there is a comprehensive physics curriculum in his school.

At the time of study Lin had recently completed her teacher training. One could position her somewhere between the independent and dependent professional. She says she follows the national curriculum and that it is convenient to mainly use the written materials but that she also uses her freedom to organise both time and content in her teaching of science: “I have much freedom here when it comes to what I do and how I do it. So one also takes part in shaping the studies a bit...”. It is evident that she has clearer ideas about possible methods and organisation of her teaching than Sage and Peter and the importance of not letting straight teaching dominate the lessons: “But it must never be a large part of the equation. One must approach things from many different directions”.

Jacob has good content knowledge in all areas of science. It is important to him that pupils understand what they are doing and that discussions are of particular importance to increase the understanding of pupils and he also tries to chat to his pupils outside formal lessons when the opportunity arises. He says that sometimes he lets the students carry out the experiments themselves and write traditional reports, but in one place he also says that: “I sometimes think that when pupils do experiments themselves that it hinders them, they are sometimes to occupied in doing something else, I sometimes feel that they do not know exactly what they are doing”. In a different place he says that he sometimes emphasises to pupils that they are doing this more too "learn to learn", not exactly to memorise all the content. Jacob is a loner in the sense that he organises all the learning of his pupils based on his own references and has little co-operation with other teachers, he says for instance that he gets facilities in the wood work shop for practical work but he doesn't plan the teaching in co-operation with other teachers in the area. When asked how the school curriculum is developed he says: "I don't know how the others do it, but I base it to a large extent on the national curriculum". Like Lin, his position is somewhere between the dependent and independent professional.

Collective responsibilities and duties towards pupils characterise Simon's professional attitude. He is conscious of the guiding principles the school work is based on, for instance the theory of multiple intelligence, and works according to them, has in fact contributed substantially to the development and organisation of a large curriculum project which all pupils and teachers take part in each year. He says he uses opportunities to integrate subjects when the opportunity arises. In the interview he says he takes part in integrating science, maths, home economics, visual arts, woodwork and social subjects. Simon's search for an effective organisation of learning and teaching in science and maths is guided by his experiments to maintain the interests of pupils in a wide ranging and difficult area of study which is known to be unattractive and of limited interest and has in addition a special position in many ways compared to other subjects or parts of the study. His actions and re-actions are evident in innovative and progressive ideas about the presentation of problems, conditions for study and ways of teaching. The results he expects is increased interest and a more positive attitude of pupils towards the study of sciences as Simon calls his area of expertise, i.e. physics, chemistry, mathematics and technology. When asked how he reacts when he receives difficult questions from his pupils which he doesn't have the answer to he says: "Then of course I admit that I do not have the slightest idea (laughs) and I admit that often I do not know". In the lessons we observed in chemistry this situation arose. Simon takes into consideration the ideas and interests of his pupils when planning his studies and believes that the study process is more dependent on internal motivation rather than in external motivation:

> You see, a teacher doesn't teach unless a pupil is ready to learn and one cannot force learning. There is always this endless struggle to find something to ignite interest which starts the process and the pupil experiences a need to learn. And the sooner the pupil assumes responsibility for his or her learning the better. Only then will the personal development increase rapidly. But as long as the pupil is so to say serving time over some exercises we expect from him then he is learning from us or his mother or father to avoid some sort of punishment and I do not think that it is healthy that this should be a question of avoiding punishment. (Interview 21.10.2005).

The expectations towards professionals are diverse. The professional, that is the science teacher, has to have knowledge of the content of the subject, its characteristics and arguments, and also the methods and ways of organising learning and teaching in addition to knowledge on curriculum, study materials and data. Finally, the subject teacher must have a view on the larger context and organisation of the school work to realise the collective responsibility in that regard (cf. Shulman, 1986; Þorsteinsson, 2003). Among the things Furlong et al. (2000) mention is specialist knowledge on things that characterise the job, flexibility to make independent decisions related to the subject or job and the solution of some unforeseen problems and finally responsibility and duty towards to the charges and working environment.

Probably none of our interviewees is an expert in all areas but rather their command in each area varies. For instance, the all have reasonable insight into the traditional content of science, cf. the content goals of physics, biology and earth sciences (National Curriculum Science, 1999) and could therefore well be classified as dependent professionals if Trausti's definition is used which includes fulfilling the responsibility authorities define as to "provide study materials and teaching in line with goals of the national curriculum" (2003, p.193). According to Shulmans' ideas (1986) the subject teacher would need to have considerably more qualities if things were to be good. He would for instance know what could support and possibly refute the presumed facts of scientific theory, what value such knowledge could have and how it relates to other theories or facts. He would also need to have good enough insight into the subject to be able to organise studies and teaching by using different approaches depending on the development and age of the pupil. Our interviewees certainly have their weaknesses when it comes to scientific knowledge which is normal, considering the subject, see the discussion above on the ever changing knowledge in science and the ever changing nature of science. They say that it sometimes happens that they cannot answer unexpected questions which they readily admit.

Discussion

It is clear that all five interviewees in this study feel obliged to cover the material "and try to cover all the main topics", as there is a national examination in science. This is an agreement with results from other studies for instance studies on back-wash effects. Set exams where much is at stake and obtain certain minimum grades (Dysthe, 2004; Phelps, 2005; Resnick & Resnick, 2002; Sigþórsson, 2007).

This affects the teachers themselves as well as pupils and their families and includes teaching methods, goals and the content of their studies. According to the seven frame model (figure 1) it is assumed that there is a coherence between content, study plans, teaching and evaluation (clear boxes) and when things are well there is a targeted effort to obtain equilibrium between all these things and the inertia state of the pupil and motivation, their study activities and interaction, development of their studies and results (cf. shaded boxes). Possibly, back-wash effects of examinations can upset such equilibrium, especially because the results in national exams are important as there is much at stake for teachers and pupils and their families as is evident from the regulation on admission to secondary school shows (nr.98/2000).

Organisation of studies and teaching

Here we make no judgement on whether the back-wash effects of examinations are positive or negative. They could strictly be either depending on how it is viewed. But they have to reflect that the interests of teachers and in fact also pupils and other stakeholders will be directed towards the goals and other content areas the examination is based on. It has its natural explanations as teachers think of the interests of the pupils who mainly have as their main goal to obtain good results according to the standardised measure which the national exams are. The teachers therefore study carefully the guidelines for the structure of the exams and also the structure of older exams. In doing so they see clearly where the emphasis is. It is for instance interesting to look at the examinations in the light of classification goals according to the system of Benjamin Bloom and co-workers where the goals of the so-called 'intellectual area' are divided into six categories. Goals are based on knowledge, understanding, application, interpretation, evaluation (critical thinking) and creative thinking. It transpires that questions on the examinations which cover the first categories are dominant in the national examinations in science in 2006, (see Námsmatsstofnun 2006, p.28). Over 80% of the items examined reflect knowledge or understanding.

If teachers or others are interested in addressing other goals, for instance a critical debate on the earth's atmosphere or global warming which was mentioned in this research then they appear according to our results to feel obliged to let that be determined by the flexibility and time once other more important goals have been met. Sage for instance feels that pupils learn best by doing themselves but there is not much flexibility for their practical work because "we have to cover all the text, that is number one”. Many have pointed out that the reputation of subjects, such as science, is primarily determined by that more weight is given to covering defined material and efficiency rather than pedagogical discourse that takes into account the ideas and special situations of pupils (see for instance Atkin & Black, 2003; Bencze & Hodson, 1999). The debate on varied ways of teaching and to give pupils time to adapt their pre-conceived ideas to the scientific ideas in the text books is certainly alive and well, but the life of the debate is primarily “on the lips of people” rather reflected in real work (cf. wording used by Zilversmit 1993).

The idea that earlier experience and pre-conceived ideas of children make a difference in the study of science has been linked to the so-called constructivist theory which has had an increased influence on the development of science education since the 1980’s. Here one can name for instance research by Rosalind Driver and others (Driver, 1983; Driver & Bell, 1986), who said that the constructivist theory postulates that learning and teaching was based on that the pupil built up knowledge and understanding, sometimes even the wrong understanding, by connecting new concepts and ideas to earlier experiences and ideas. In addition it would be first and foremost dependent on the responsibility of the pupil himself whether learning took place: his interaction with his environment and the language used was pivotal in deciding what sort of meaning, ideas and concepts he had on his mind. During the last quarter of the century researchers in science education have become more interested in this (Bennett, 2003) and thereby the organisation of the school work which reflects the shaded boxes in the seven frame model. In this respect, the so-called constructivist theory has probably been most influential with reference to the importance of language, social conditions and the environment. At least two of our interviewees see a tendency towards this direction in their organisations, Jacob and Simon.

Decision making and professionalism

Teachers make decisions based on many factors and they take on varied responsibilities in their jobs. In this study science teachers in upper primary and lower secondary schools were interviewed. They all have obtained specialist knowledge in the area through general teacher training but in addition they have specialist knowledge on the content of the subject, how to teach it and appropriate ways of learning, learning situations and problems.

This generally agrees with what Shulman (1986) said about the specialist knowledge of subject teachers which he considered to be of three types, in addition to general knowledge or pedagogy that is knowledge of the content of the subject and appropriate methods and approaches. Last but not least there is the knowledge about overall organisation, curriculum, study materials and data which Shulman called curriculum knowledge. In this respect the view of the general context of the school work and the collective responsibility for its organisation is important, both in lateral and vertical curriculum knowledge. Trausti Þorsteinsson (2003) points out that the demand for such overview and the collective responsibility of staff in institutions like schools has been increasing together with the increased right of people to access information and therefore the position professionals has been changing concerning ethical values and collaboration (2003, p.190). Researchers such as Hardgreaves have discussed these changes under the heading “the new professionalism” cf. the title of Hardgreaves book from 1994. Trausti refers to studies which indicate that the so-called dependent professionalism where teachers follow exactly the national curriculum and other directives is becoming less important and that independent professionalism where teachers have the freedom to decide on study materials and methods can hardly work because of the tendency of the authority to take professional responsibility away from the teachers. What is left is the new or the collaborative professionalism which is characterised by teachers abandoning an individual role in the classroom to more collaborative working methods where co-teachers, pupils and parents are co-workers. Such development results in that teachers serve the common interests of schools as institutions and have to put forward for professional discussion their ideas on study goals, teaching methods, areas of study and other professional problems (p.196-197).

Trausti studied the characteristics of professionalism amongst 285 teachers in North-Eastern Iceland which he published in an M.Ed thesis in 2001. The majority had the characteristics of collaborative professionalism. Many were also classified as independent professionals. Only very few were classified as dependent professionals. This appears to be the other way around when it comes to our interviewees in this study. Judging by their replies and ways of working they mainly seem to fluctuate between independent professionalism and dependent professionalism. Even if the sample here is small it can be argued that the attitudes and working styles of the five teachers are to some extent characteristic for Icelandic science teachers. And perhaps it can be said that the nature of the subject isolates them to some extent in their work: “one is a bit like an island where one doesn’t get any ideas from anywhere else” said Sage at one point. When asked about collaboration with another teacher because of practical teaching Jacob said: “I‘m in a totally different gear from him so I just do this myself and have my ideas about this”. In another place he says: “...there is a lack of co-ordination and many physics teachers are a bit lost in this”, which indicates that science teachers do not agree internal issues.

Final remarks

It cannot be ignored that the compulsory school is meant for all which means that we must carry out learning and decision making in science considering everybody’s needs. Even if our interviewees are relatively well versed in the goal and content of the subject more is required when such a deep, wide and ever changing subject is considered which in addition is directed at a varied group of pupils with different needs. The work of science teachers is challenging and demanding but at the same time rewarding. The collaborative professional has obligations and responsibilities towards his colleagues and the school system as a whole but not least to the pupils themselves where communication and the understanding that learning does not take place without the active participation and both inner and outer motivation of pupils. The results of the study certainly indicate that there is a tension resulting from trying to meet both the needs of pupils and the demands of the system for results, but it is clear that all our interviewees show compassion in their jobs and are guided by the important point of view that Strike and Soltis emphasised : “ethical thinking and decision making are not just following the rules” (1985/2004, p.1).

Learning science with ICT[1]

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This small-scale research study reports on the use of information and communication technology (ICT) in school science and the way in which the views which teachers have of science teaching are reflected in the way they use ICT. Some research on teaching indicates that teaching practices are often subject-specific. Other research on science teaching suggests that the nature of school science is such that teachers could incorporate the use of ICT quite effectively in their teaching practice. Earlier research on the origins and production of national curriculum on information and technology education found that those preparing the national curriculum guidelines issued in 1999 (Menntamálaráðuneytið, 1999b) had overestimated the capacity of the existing school system to absorb fundamental change in teaching practice called for by using ICT (Macdonald, Hjartarson & Jóhannsdóttir, 2005). The national guidelines for science released in 1999 (Menntamálaráðuneytið, 1999a) has three components: The nature and function of science, content areas (biological, geological and physical sciences) and skills and methods needed for science. The use of ICT is recommended in several of the objectives in the national guidelines.

The research study described here looked at the use of ICT by five science teachers. To describe and analyse the use, the authors drew on the Computer Practice Framework developed by Twining (2002), on a model of the suitability of ICT for developing procedural knowledge in science (Baggott La Velle, McFarlane & Brawn, 2003), and on the different roles given to students when ICT is used in science (Newton & Rogers, 2003), such as receiver, explorer, creator or reviser.

A purposive snowball sample of five respected science teachers in the urban southwest was selected and all five teachers were willing to discuss their views on science teaching with us and grant us access to their science classrooms for about one hour. The discussion started with description of lessons that went well and we gained a good idea of their views on what works well, the problems faced in teaching science and in using ICT. We returned a few days later to follow a lesson selected by the teacher, and this was followed by a brief discussion of points arising from the observation, some of which were related to the earlier discussions.

All five teachers used ICT, though in different ways. Two of the teachers used it mainly to present information to students in classes in slide presentations (Peter, Saga), casting their

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students in the role of receivers. Saga referred to technical difficulties and poor access to computers, as well as her own inability. Peter did not use a data projector at the time of the study, using a TV monitor instead to show slides. Two expected their students to use ICT quite a lot, casting them in the role of explorers, one as a means for students to access relevant information (Lin) and the other more as creators, as a way of recording, working with and presenting information (Símon). A fifth used ICT for communication with students after school hours, showing a pastoral responsibility (Jacob). In addition, Lin, Símon and Jacob presented information in class with a data projector, so their students were also cast in the role of receivers. All five teachers expected students to be able to complete homework assignments using a word processor or a program to prepare slides, though it is questionable the extent to which creativity was encouraged. All the teachers indicated that most of the ICT skills which students were expected to use were taught elsewhere.

The most striking result of the study was that in this small sample subject-specific use of ICT was vague or weak. Indeed the science teaching practices described to us by teachers and which we observed reflected to a minimal extent key aims in the national curriculum on the nature and function of science and the skills and methods of science. Instead it seemed that each teacher had their own “theory of teaching” which guided the extent to which they used or wished to use ICT in school science classes. Consequently the emphasis seemed more on content than process, knowing *what* rather than knowing *how*.

Introduction

This research focuses on the use of digital technology in the learning and teaching of science. By digital technology we mean information and communication technology (ICT). The digital technology we deal with is found in three forms. Firstly it is found as hardware, such as computers, projectors and other equipment, secondly as software such as programmes and multi-media options and thirdly as information or communication technology systems, such as the intranet of schools and the Internet.

Figure 1. The categories of goals in science are intertwined in one whole (The Natural Curriculum in Science (1999, p. 8)

Science as a school subject is more wide ranging than people generally think (Note: In Icelandic there are several terms for science such as natural science or the 'science of reality'). This is evident in the introduction of the national curriculum in science which was in effect at the time the research was carried out, and will be until 2010: " It (science) covers the wonders of nature in uncountable ways such as matter and forces, the universe, Earth, and life" (Ministry of Education, 1999a, p. 12). Science thus covers both living and non-living things in nature. Three main categories of the goals of the national curriculum cover both content and methods. They are:

1. The role and nature of science
2. Content areas:
    - Physical sciences
    - Geological sciences
    - Biological sciences
3. Skills and methods

In all categories there are instructions to use ICT in the study of science (Ministry of Education, 1999a, p. 9 & 12) aimed at the goals set in the last category which are explicit in this regard (for more detail see the aims and objectives under *Skills and methods* in the curriculum). There is an emphasis that pupils understand in what way science influences the thinking and way of life of modern man and the development of society. There is also an emphasis on pupils becoming familiar with the scientific approach, through which they should be able to formulate a question, plan, record and analyse data, interpret, evaluate, present and communicate the results. "With the assistance of technology and various software new types of practical work become possible and in the goals of the national curriculum in science it is expected that these possibilities are well used from the start of schooling"(Ministry of Education, 1999a, p. 12). There is also a strong emphasis on the use of ICT in making measurements, recording them and calculations, as is the case in neighbouring countries (i.e. National Research Council, 1996, p. 175). All the categories of the goals in the science part of the national curriculum are to be interwoven into one whole which forms a natural development in the studies of each individual (Figure 1). There goals are set for the selection of topics from the three main areas of natural sciences, i.e. the physical, geological and life sciences, are common as regards the methods and skills of pupils and their attitudes and understanding of the nature of the discipline and its role in modern society (Ministry of Education, 1999a).

Towards the end of the last century a special curriculum from ICT also took effect, the *National curriculum for compulsory schools: Information and technology education* (Ministry of Education, 1999b). The ICT curriculum is divided into three areas, design and carpentry, innovation and the practical use of knowledge, and information education. Here general goals were also set with regard to computer literacy that was to be integrated into teaching and learning in all subject areas in the compulsory school. A statement on the use of computers in compulsory schools makes clear the expectation that ICT be used in all studies:

> Applying information technology and using computers is an approach should colour in all aspects of society. Therefore, it is essential that such technology and work methods must have an appropriate place in the compulsory school. Teaching and learning in all school subjects must reflect this. (Ministry of Education, 1999b, p. 10).

The aim of the research reported on here was two-fold. On the one hand the ideas of five teachers on learning and teaching in science were explored and how their professional identity reflected the special position of science as a subject (Thorolfsson, Macdonald and Lárusson, 2007). On the other the aim was to understand how they used ICT in their teaching of science and in what way science was special in this regard. The results from the first part of the study indicated a certain tension among the teachers which resulted from the fact that they had to keep to a plan and finish the material and at the same time take into consideration the different ability of the pupils to deal with the material and emphasize the skills and work methods which characterize science studies. The participants were all of the opinion that there was not enough scope for critical discussion, practical work, measurements and observations, which could be considered the hallmark of science as a school subject.

One of the things that prompted this research was the approach and results of some larger research studies in the UK on the use of ICT in the work of schools (John & Sutherland, 2004). It has long been stated that the teaching and learning of each school subject has a special culture or tradition, that there is a *subject specific practice* (Lederman, 2001; Shulman, 1987). A cooperative project between universities and schools was implemented to research this. A few school subjects and traditions within these were selected. In our research we tried to see if such pattern could be discerned in the teaching of science among the five teachers taking part in the study, or whether we would find a support for the idea that each teacher had his/her own personal hypothesis of teaching (see Bjarnadottir, 1993) and that that their teaching was more influenced by this than a subject specific culture or tradition.

Here we report on this aspect of the study, i.e. how the five teachers used ICT in their teaching of science and at the same time what mainly influences their teaching, i.e. to what extent the special position of the subject influenced their teaching and to what extent it was influenced by the professional theory and perspectives of individual teachers. In analysing and interpreting the results, the model of Peters Twining (2002), *Computer Practice Framework* (CPF), was used, as well as the ideas Newtons and Rogers (2003) have put forward on the use of ICT in science teaching as well as the model of La Velle, McFarlane and Brawns (2003) on the use of ICT in science teaching as regards working methods and skills in the collection and analysis of information.

Research into the use of ICT in the teaching and learning of science

Judith Bennet (2003) reached a few important conclusions from recent research on the use of ICT in the teaching and learning of science. From this it seems that the most important part of the organisation of studies where the use of ICT is emphasized is the teacher and the professional theory which characterised his or her teaching. If ICT was to become and import and part of the teaching, traditional in-service courses were not enough, there was a need to provide a good support within each school, there had to be a flexibility to implement the arrangements needed and access to equipment (Bennet, 2003). The hardware and software which is of most importance for science studies had to be available where the studies take place, not in a specially equipped computer room. According to Bennet, research also appears to show that ICT offers innovative ways which awaken and support pupils interest and strengthens the understanding of pupils on scientific ideas and concepts and that the use of ICT in the collection of data, measurements and recording (data logging) and modelling may be pivotal as it saves time and in dealing with data and thus leaves more time for discussions and the interpretation of the date, which is one of the most important aspects of learning (La Velle et. al., *British national curriculum in science*). This is about a few case studies where the researchers work closely with the teachers themselves and those involved in teacher education. In the first case study a triangulation was used to research the role of ICT in learning and teaching where 11 and 12 year olds were studying electric currents, using amongst other models. It turned out that the theory and practice of teaching were important with regard to the role of the student in the process and thereby their results.

Some research has been done on the special position of some subjects in their use of ICT. Hennessy, Ruthven and Brindley (2005) for instance investigated how teachers in secondary schools used ICT in English, mathematics and science. In interviews with subjects it was apparent that there was a strong tendency to keep to certain traditions and the special status of the subject and as a result it was possible to detect a resistance to change which the use of ICT might require. At the same time it was noticed that traditional curriculum and exams worked against change. But despite this the participants in the research saw reasons for following rapid technological change of the knowledge society and the researchers felt that they could see a slow development in the organisation of learning and teaching resulting from the influence of ICT.

Peter John (2005) also researched the use of ICT among subject teachers in mathematics, science, music education, foreign languages and geography. He reached similar results i.e. that subject teachers were willing to integrate ICT in to their teaching as long as the computer technology didn't led to radical changes of the basics on which the relevant subject was built. In his article John uses interesting metaphors to emphasise the cautiousness of teachers with regard to new technology. ICT is for example likened to the "Trojan horse" and reference is made to the famous words of Marchall McLuhan: "The medium is the message (John, 2005, p. 480) which refers to the structure and potential use of the medium (ICT) to have strong control of the content and organisation when it was used. In John's research i.e. an interesting perspective was found among teachers that students had a tendency to regard a digital simulation as being one of the many kinds of computer games and therefore it was not guaranteed that they achieved the intended purpose.

The use of ICT in learning and teaching has been the subject of a few studies in Iceland. In this regard the emphasis on ICT in the national curriculum in nursery, compulsory and secondary schools from 1999 and varied options for study at all stages of schooling, not least in universities has been influential. An example is an addition of a computer and ICT in the line of study at the Icelandic University of Education in 1998, lines of study offered at the University of Reykjavík related to the use of computers and pedagogy and five years ago ICT became a special elective in the undergraduate studies in the School of Education at the University of Iceland (Earlier Icelandic University of Education). In June 2008 a research group in this area was established, RANNUM, which focuses on research in ICT (see http://wp.khi.is/rannum). At least 30 master's thesis in the area of information technology and computer use in school work has been published in the past 10 years (Macdonald, 2008).

From 2002 to 2005 a research project called NámUST (http://namust.khi.is) was implemented with the support of strategic policy on IT and environment. There the use of IT in all school levels was examined. The objective of the study was to find out what influence the use of ICT had for pupils and learning, for teachers and teaching, and for the school as an institution. The results showed that the use of ICT in lessons was generally limited, advantage was not taken of the possibilities and their use was repetitive. The occasional teacher used their own initiative in using ICT for teaching and learning rather than there being a clear policy being implemented in schools (NámUST, 2005) and the participants felt that ICT was useful in teaching which was based on creative project work where the traditional timetable was put aside and teachers worked together. But it was clear that the integration of ICT and subject teaching had not been accomplished. A study from 2005 showed similar results (Macdonald, Hjartarson & Jóhannsdóttir, 2005), where the authors reach the main conclusion that the emphasis in the curriculum in 1999 on ICT had probably overestimated the abilities of schools to implement the changes demanded by the use of ICT.

There are not many studies in Iceland that were focused on the use of ICT in subject teaching and skills of teaching. Manfred Lemke (2005) did a survey based on replies from 1088 teachers about their own skills in computer use. At closer examination of skills in different subjects it appeared that the situation was best in three subjects: sciences, social subjects and mathematics. Science teachers felt most confident about their own skills in relation to the groups and all well above average. Teachers of art and crafts were among those who felt they had the least skills. The difference between the groups was mainly evidenced in the use of spread sheets. It is interesting that Lemke was of the opinion that the skills of teachers were stronger in subjects “where the use of computers has a longer tradition” (Lemke, 2005, p.58).

Aðalbjörg María Ólafsdóttir (2009) investigated the situation of six visual art teachers and found that even if the teachers thought they were using ICT in their teaching, the use of ICT turned out to be minimal and mainly in preparation for the teaching and the presentation of new materials but to a lesser extent as a support to the studies themselves. Only very rarely did pupils get exercises which related to the possibility ICT offers in changing or supporting their studies. The visual art teachers in the study did not seem to think they were responsible for following the national curriculum in ICT which is interesting in light of the instructions which were referred to earlier from the national curriculum.

Svava Pétursdóttir is currently engaged in PhD studies at the University of Leeds. There she is researching the role of ICT in the teaching of science in the 7^{th} to 10^{th} grade in Iceland. Her research is based on questionnaires and interviews. In an interview with Svava it appeared that according to her data the most common form the use of ICT takes in science teaching is in the collection of information from the internet on selected topics and presentation of the information using power point or in reports made by the aid of a word processor. The teacher’s use of the power point software appears accordingly to be considerable in general teaching at the time when Svava collected her information.

Research into the setting of policy and the developments in ICT and digital study materials in Iceland are part of a larger research project which was carried out by OECD between 2007 and 2009 (OECD/CERI 2008,2009), revealed that in Iceland it is possible to teach all subjects except for ICT itself without using computers. The policy turned out to be set by the authorities but the implementation of the policy was based on the initiative of people in the schools through the making of study materials and information and the application for grants to do so. As with Bennett (2003) it turned out that teachers need more support and there was a need to create a forum, for instance on the internet, for teachers to form a community on work and teaching practices. This seems to be a valid conclusion because advice to teachers on ICT is limited in Iceland and specialist organisations in this area do not seem to have made this a priority. Public funds used to make digital study materials are channelled through Námsgagnastofnun and few special funds and does not allow for large projects or initiatives (Macdonald, 2008).

Methodology

In this research the use of five science teachers in compulsory schools and their use of ICT was studied, the nature of their use and whether it was mainly influenced by the nature and the culture and tradition of the discipline or the professional theory of each teacher.

The five teachers, two women and three men, were interviewed for fifty to sixty minutes. The interviews were carried out at their workplace and their teaching was observed. They were all working or had been working as subject teachers in science in the middle grade or the lower secondary level. The participants were selected by purposive sampling (McMillan, 2008) because of their specialist knowledge or education as science teachers and also their experience of such teaching. The first one to be interviewed was selected because he was known for her interesting organisation of learning and teaching and is educated in the teaching of science. He identified the next two participants as interesting teachers and finally two more were selected with regard to gender, education, broad teaching experience and the researchers had heard of them as experienced and progressive teachers of science. Four taught mainly in the lower secondary and partly in the middle grade, and one mainly in the middle grade.

Collection of information took place in the classroom of the participants, the interviews were semi-structured and the teaching observed. An interview can develop in many directions depending on the goal of the study and the theoretical angle (Brenner, 2006). On the one hand this can be an interview based on a deductive approach where objective information is gathered using a quantitative method. On the other hand an inductive approach can be used when the interview is more like a conversation, it is open, it is not particularly directed or determined in advance where the conversation will take the researcher or the participants. In this case one of the most common ways in these methods was adopted (McMillan, 2008) i.e. the interview was semi-structured. The collection of information and analysis was primarily characterised by a qualitative method. The questions were open but at the same time a clear framework for the interviews was used as much as possible. In semi-structured interviews the main focus is on following a certain theme. Kvale (1996) describes such an approach as a sequence of themes that have to be tackled in the conversation but at the same time keeping the possibility for flexibility open, changing the order of the themes if needed and asking in more details on some issues if needed, follow up and to get clearer information with regards to context and particular situations. In this research such procedures were adopted.

The interviews took place at a pre-determined time and venue in consultation with the interviewees. The researchers returned to the venue and were allowed to observe the science lessons taught by the participants. After the teaching was observed participants were re-interrogated in order to shed light and certain aspects and in order to contextualise what was observed. In most participatory research researchers place themselves into an environment foreign to them and need to be open to understand the context, traditions, culture, communication and other issues they encounter within that specific working culture (Anderson-Levitt, 2006). Unspoken rules, traditions and culture all took on a different meaning within the five schools being studied, by the pupils, teachers and other actors which came into the picture. Teaching practices, modes of communication, behaviour and the organisation of the environment all bore testament to different school cultures.

Data analysis

The interviews were recorded and transcribed and field notes recorded with detailed information about the situation of the five teachers and the information analyzed with regard to the overall context. In analyzing the information, standard procedures of analysis of qualitative data were used, i.e. they were examined and interpreted in view of what the participants said and did (cf. *emic perspective*, Banks, 2006) and an attempt was made to elicit the meaning of what then appeared. Important interpretations were sought for in the information and they were then tested and revised as necessary by comparing items or themes. In this way the researchers tried to find a valid and fair meaning of what transpired (cf. Kvale, 1996). Kvale discussed interpretive analysis in terms of a hermeneutical circle, which could for all purposes be infinite (1996). In this way an attempt was made to examine relationships between on the one hand what the interviewees said and what they did on the other, internal consistency and possible contradictions.
When categorizing the information, support and references were sought form three sources. Firstly, the model of Peter Twining (2002), about the use of computers, Computer Practice Framework (CPF) was used. The model is based on three fundamental questions on how the use of computers in schools is expressed, i.e. to what extent is ICT is used (a quantity dimension), in what way (a focus dimension) and finally to what purpose, which essentially means to what extent ICT influences the content and methods of learning and teaching (a mode dimension). In our analysis, we primarily focused on the mode dimension, which Twining attributes considerable weight to in using the following three categories for the effect of the use of ICT:

- *Support*: Here it is the same content as in traditional teaching but faster and more automatic methods of study. Minimal changes in the content and organization of learning and teaching in other respect.
- *Extension:* Some changes in the content, and or, methods from what is done in traditional teaching without ICT. However, the same goals can be obtained using ICT.
- *Transformation:* Changed content, and or methods, the goals would not be achievable without ICT.

In additions to Twinings CPF-model, the ideas of Newton and Rogers (2003) on the two-fold use of ICT are also used. Newton and Rogers mention two types of purpose for using ICT referring to the nature of information and communication technology. That is on the one hand to use the specific advantages of the computer, e.g. the use of spread-sheets in recording data, faster calculation and analysis and interpretation of results and on the other hand to use ICT as an opportunity to dig deeper into the subject, obtain information, discuss it in a critical ways, create, review and communicate. In this context the learning activities of pupils can be described in different ways as they can at the same time be receivers of information and data, explorers, creators or advisors.

Finally, the research of Baggott La Velle and co-workers (2003) on the use of ICT to strengthen the knowledge and work culture of pupils was used. Learning science means to learn about topics and content (*substantive knowledge*) on the one hand and on the other hand adopt certain procedures, ways of working and skills, and skills to evaluate knowledge, obtain it and analyze data and information (*procedural knowledge*). Baggot La Velle and co-workers (2003) and also Watson (2000) and Bennett (2003) point out that the use of ICT can easily function as support to both, i.e. learning about concepts (cf. *conceptual knowledge*), and not least to strengthen work practices and knowledge and skills in practical work (cf. *procedural knowledge*). The same studies show, amongst others, that these two things are mutually interdependent and therefore it is preferable to work with the pre-ideas of pupils with both in mind.

This is reflected in the emphasis on methods (cf. *process standards* in mathematics) on the one hand and content (cf. *content standards*) on the other, which has been prominent for the past 30 years in connection to learning and teaching of mathematics of the natural sciences. In the natural curriculum for compulsory schools for mathematics (Ministry of Education, 1999c) clear examples can be found in this regard, i.e. the categorization of goals into methods and content where there is an emphasis on to “give an equal weight to these two things and that pupils who experience both as an important part when learning mathematics” (p.7). It is for instance expected that pupils can define a real problem, identify the mathematical tools (symbols, concepts, rules) which are needed to solve it, giving appropriate weight to each and devise a method that produces a solution; finally the can interpret their solution in appropriate context (ibid). Corresponding examples can also be found in science where real data are collected and they are processed in a comparable way as described above.

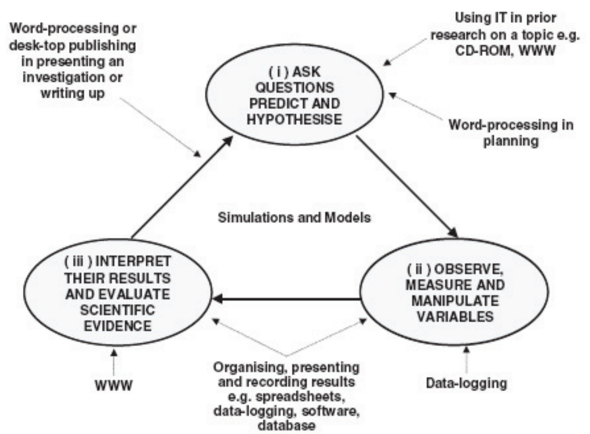

Figure 1: A model of the cyclical process of science that can be used to structure experience of science at the school level with some examples of current use of ICT from McFarlane 2000

Figure 2 A model of uses of ICT in developing procedural knowledge (from La Velle, McFarlane & Brawn, 2003)

Towards the end of the last century the public debate on learning science "for all" increased and has continued to increase until this time. It is assumed that knowledge and understanding in science is not only obtained by learning *static knowledge* from books but that for the youth of society it is not less necessary to get acquainted with ever changing reality by carrying out their own research on it. (McCormick, 1997; Miller and Driver, 1987; Miller and Osbourne, 1998). Baggott La Velle and co-workers (2003) point out the qualities of ICT when considering science learning of this nature. Reference is made to improving skills of pupils in work practice and knowledge in this context (Figure 2); pupils make use of ICT to ask questions, advance hypotheses, search for information, collect data, record, calculate and analyze and present results, communicate and discuss. Below, the *methods*, *practice* and *skills* will be discussed cf. the names of corresponding goal categories in the national curriculum of science (Ministry of Education, 1999a) in a similar sense as *procedural knowledge* as used by Baggott La Velle and co-workers.

In the light of the above, an attempt was made to map the use of ICT among the five teachers and describe it with regard to the goals described here. The use each of the teachers made of ICT was thus analyzed with the following in mind:

- The importance of ICT in the learning and teaching of science. What importance does each teacher attach to ICT?
- The purpose of ICT. Is ICT used as support, addition or transformation cf. Twinings' CPF model.
- Learning, which include methods, practice and skills in obtaining knowledge, cf. the ideas of Baggott La Velle and co-workers. To what extent is such practiced used with or without ICT?
- What is the role of pupils when ICT is used? Are they the receivers of information and data, investigators, creators or revisers?

Results

In the results the four factors mentioned above are explained for each participant under four sub-headings. The same code names will apply here as in an earlier article (Þórólfsson, Macdonald and Lárusson, 1997) when referring to comments or actions of interviewees. These are Saga, Peter, Lin, Jacob and Simon.

The importance of ICT in teaching and learning

Here an attempt is made to paint a picture of the importance of ICT, the learning and teaching of science as it appeared to the five participants at the time of the study. A quantitative study was

not done but on an attempt to assess was made based on interviews and the examination of conditions of how important ICT was in the learning and teaching for each individual.
ICT was relatively unimportant to Saga. She did have continuous access to the computer connected to the internet and projector in her classroom but appeared to make limited use of the equipment and then only to support the transmission of materials. She said she would like to use a specially equipped classroom more than she did but that that classroom was almost without exception taken.

The use of ICT appeared to be almost non-existent with Peter. He used a computer, in fact his own computer, to support lectures of the materials. Apart from that he did not use ICT in the teaching of science and his students never used it. He said he had limited access to equipment and tools after school but he had been promised that it would provided.

Lin used ICT to a considerable extent. Her school was well equipped with laptop computers which she often used, amongst others, by free browsing on the net. She also used a computer and a projector to present her power-point presentations when she covered her materials. "I will be getting a projector for the ceiling… it just has to be installed".

Jacob appeared to use ICT seldom directly in his science lessons, he said though that he got his students to write essays, collect information from the internet, make posters and prepare presentations but not directly in the science lessons. When asked about the access to common software in connection to science learning he said: "…that is taught in computer science (power point), word and excel and all that".

It was without a doubt Simon who used ICT the most. He also used it in more different ways than for example Lin who also used digital technology quite a bit. Simon used all sorts of equipment and tools, whether digital or not, to sharpen the understanding of pupils and conduct the learning and teaching in agreement with the goals of the national curriculum relating to the practice, skills, and the role and nature of science. He brought up some interesting ideas on the use of ICT, for instance to show a computer model of the solar system which moved planets and showed their positioning in the same way as they are in reality.

The purpose of using ICT

According to Twinings' CPF model one can discern three types of purpose when using ICT i.e. in relating to whether information and communication technology is used as support, as an addition or extension, or to transform the teaching.

Saga used ICT almost exclusively for support. She said she was looking for more ways of using it rather than direct transmission but she mentioned that she had not been able to develop such teaching practices, for instance by “interactive assignments”, to use her own words. She claimed to be looking for ways to use the internet to look for pictures but it was not going well. Now she said she was looking for something “interactive” but that too wasn’t going particularly well. She saw it as a problem not to have Icelandic text on the internet to look for and said herself that she was not very “adapt or diligent in searching the net, lacked ideas and co-operation with other teachers”. Saga felt that there was a need for short courses on how to teach science, that there was a greater need to learn how to do practical teaching than to learn the content of the discipline. She brought up interesting examples about the need for digital measuring tools, thermometers, scales and others.

ICT was almost exclusively used as a support for Peter. He used his own computer and television screen to communicate materials to the pupils. One can though say that ICT to some extent was an addition as he said that he sent the pupils study plans and summaries for each lesson by email and put them on the screen later in the classroom. He had only recently gained access to the internet and still hadn’t started using it in teaching.

Lin used ICT as support and as an addition. Her pupils had access to lap-top computers connected to the internet and they could search for materials connected to the teaching materials: “Then they are carrying out some sort of search there or looking at particular websites”. People use, amongst other things, pictures from the internet and a projector to make drawings on poster. In her opinion the projector is useful in science teaching. “…when one is trying to show different pictures and other things one finds on the internet, what one doesn’t find in books.” Lin participated in the creation of a website on simple and inexpensive physics experiments. She said she used the internet to look for answers if she didn’t if she wasn’t able to answer questions straight away. She also told pupils they could do so if they didn’t get answers from her or from the textbook.

It was difficult to assess Jacob‘s direct ICT use because he assumed that pupils did such work largely independently outside regular school hours. It is however evident that his use of ICT was primarily an addition and to some extent a support. He directed his pupils amongst others to websites which assist in solving equations for chemical reactions and to obtain information on topics for essays and presentations. In his view the debate on the role and nature of science in society, for instance on genetic research and the effect man has on the environment, increased the interest students had towards science. Such discussion must have guided pupils to the internet, for instance to the Web of Science (University of Iceland) to obtain information about the topic even if there was no evidence on the direct use of ICT in Jacobs teaching.

The diverse use Simon made of ICT appeared as support, addition and extension, and also to some extent to transformation to the way of teaching:

> In the chemistry now they were supposed to select a topic and they were to discuss, actually, to take one of the elements and describe how it appeared, what it is used for and try to find examples for man to find it in nature and how it affects us as humans to work with the substances… They then have to present this in different ways except that everybody should create a small website with their own materials which is then combined with everyone's work in one package. And those most technologically advanced are going to have something extra, would like this digital board here (from an interview 21.10.2005).

Simon said he used the projector a lot but that he didn't always have access to it since there were only two projectors in the school. He made pupils access information on the internet and he himself got lots of materials from there to use in the teaching. Simon managed the first lego competition in his school and that was a clear example of transformation brought about by ICT because it required a completely different set up than a traditional classroom and pupils took part in programming and various practical learning related to programming, recording data etc. He also used a spread-sheet in his teaching from the fifth grade up to the tenth grade where pupils collected data, recorded, analyzed and made a visual presentation.

Practice, work methods and skills (procedural knowledge)

Baggott La Velle and co-workers (2003) studied how ICT could be used in teaching when the emphasis would be on knowledge and skills associated with procedures such as practice, methods and skills of various sorts such as research skills, collection of data, analysis of data and presentation and evaluation of results cf. the braid model mentioned earlier from the national curriculum for science in compulsory schools. Saga appears only to a limited extent to have adopted such teaching practices and ICT was hardly evident at all amongst her and her pupils in their studies which could be related to practice and skills. She said she had never used digital measuring tools in her teaching such as scales or thermometers but mentioned however interesting examples on the importance of such tools. She said that she used sometimes pupil experiments or demonstration experiment which she called "plays". Pupils wrote reports after the experiments and she read them over but said that the pupils' understandings of what was going on were limited. In spite of pupil activity in practical exercises she said that she feared that the understanding of many was limited and gave amongst other things an unsuccessful reading off a glass thermometer (2 degrees Celsius instead of 20 degrees Celsius): "So one can learn something but not connect it to, so there is a connection missing." When asked what was primarily missing to teach difficult things she felt that there was more missing than equipment and tools: "…or maybe a method, I think there is rather missing a method." And she mentioned her own ignorance in methods as an obstacle: "I just don't know what to ask for" (when discussed what sort of support teachers needed). She carried out practical exercises and experiments both in the classroom and outside school. Saga said she had prepared a box with materials for practical exercises and other things for teachers in the younger classes but according to her they didn't seem to have gotten the knack of using it. It turned out that these boxes were not in use at the time of the study.

We took special note of the fact that Peter said he did not make his students do experiments, he rather did himself small experiments at the same time as he covered the material: "I am not much for making them do the experiments themselves. I have felt that they just don't serve the purpose…I think that they gain more if I do the experiment." The exercises presented to pupils were almost always written, that is questions, problem solving sheets and exercises from the textbooks. It was therefore evident that Peter's teaching practices were not in line with the goals of work practices and skills, with or without ICT. On the other hand pupils were observant and appeared active when Peter wanted to show different phenomena with demonstrations.

Lin seemed to have made some progress in these matters. She said that the pupils learned in different ways and that they needed different approaches in their studies: "It suits some to have practical work and others want to have text only." Lin uses varied, everyday things when she organizes practical work, she uses for instance a plastic page as a model to show how a cell and cell membranes work. "They may remember if one takes examples they know and try to compare it to something from their own world." Lin used microscopes and uses equipment in experiments, "… but I try usually to build up experiments that do not require complicated equipment and tools, but I would rather have something one knows." Lin says that she herself uses a spreadsheet but she has not mastered how to make pupils use it. Outdoor teaching was a fixture in the school timetable where there should be opportunities, all sort of data collection, recordings, measurements, analysis and calculations. In spite of emphasis on work practices and skills, Lin has some way to go in order to use ICT for that purpose.

Jacob said he sometimes lets pupils do experiments themselves and write traditional reports, but "…I feel sometimes that in the pupil experiments that they do something themselves that hinders them, they become absorbed in doing something, but I think that sometimes they do not know what they are doing." This could have lead to the conclusion that strengthening work practices and skills was not a priority in the education of his pupils. However, one elective project should be mentioned where his students built a small vehicle according to criteria he set and then took part in a competition where the vehicles had to drive along a specially made track and solve problems. The pupils did most of this work independently at home so it is quite unclear in what way ICT was possibly involved in light of what Baggott La Velle and co-workers (2003) had thought. (cf. figure 2). Jacob said he made it quite clear to his pupils that the study of physics was difficult but it was a training in learning and strengthened logical thinking: "…I feel it is most important to know to learn, to learn to learn,… it (physics and chemistry) challenges the brain and sharpens your thinking.". In this case Jacob is describing circumstances where work processes and skills related to ICT could precisely be important if used appropriately. As with Saga, Jacob said he uses balances but not digital measuring tools. But contrary to what Saga said,

Jacob wanted to have more depth in the subjects in the teacher education i.e. content knowledge, while Saga wanted more emphasis on work processes and skills.
Enquiry, which included work processes and skills seemed to be of great importance in Simon's teaching plans. He said he often practiced such teaching by weaving together mathematics, science and technology: "Yes, you see, then I can have, you see, all sorts of blocks and scales and units… the math is never far off when you are dealing with science". Simon said it was of concern for him that practical skills and knowledge were held in higher esteem than academic knowledge: "I ask myself often, you see, that a pupil who can take apart a motorbike and re-assemble it but cannot find the common denominator in basic fractions and he doesn't know where to put 'y' in a written text. I feel that in reality he possesses remarkable knowledge to be able to take a motorbike apart and put it together again, a much more complex skill." Based on the conversation one could infer that Simon thought that it included a lot of knowledge on the attributes and nature of matter and equipment to be able to practice with such results and such knowledge and skills, and that such knowledge and skills should be nurtured although it would be more difficult to test it in a formal way as with algebra in written exams. The role of ICT in strengthening work practices and skills in Simon's teaching appeared in many ways, including programming in the lego projects, in the recording of data and the analysis using spreadsheet, in presentations using power point and ideas about making web-sites which the pupils worked on.

What roles do pupils play?

Pupil's learning activities can appear in different ways depending on what teaching methods are used. Pupils can at the same time be the receivers of knowledge, information and data, explorers of ideas, creators who put information into a new context or revisers that is ie. analyse available date and revise using different methods. Saga's pupils were primarily receivers. She said she did not use conversation or discussion as a teaching method: "There is not much chatting…. I am not good at it". When asked about independent computer use by pupils in the computer room, for instance letting them go on the internet and look for games and experiments relating to physics, Saga stated it would not work; pupils would select different materials to examine. And during the same occasion she said that she had tried to use the science lab "but they couldn't be bothered". Even so she said that she sometimes referred her students to the science lab. Saga clearly thought that the pupils were governed by outer motivation: "…something tangible, something they can return back to me, it just works like that" (when discussing projects and how to evaluate them). She wanted short courses on particular teaching practices in science (cf. Shulman's 1987 discussion on *pedagogical content knowledge*) rather than content and knowledge, because that was her weakness. She clearly found it difficult to capture the interests of the pupils, to make them more explorers and creators in science, not only receivers.

Peter only taught mathematics and physics at the lower secondary at his school and had on his own account good background knowledge on those subjects, as he had earlier studies computer science and electrical engineering at the University of Iceland. In using participatory methods this could be confirmed, i.e. his good command of the subjects. In a lesson in the ninth grade which was observed, he discussed the movement of heat and maintained the attention of the pupils with interesting, interactive discussions and conducted at the same time a small demonstration which captured the attention of the pupils. From the interview and field observation with Peter one could conclude that pupils were exclusively receivers but at the same time it has to be said that they seemed to be considerably "active receivers", i.e. their learning activity appeared to be considerable under the conditions in which they were observed, which has to be the same issue when it comes to study results.

Lin's pupils seemed to be at the same time receivers, explorers and to some extent creators. She clearly took into consideration the different ways in which pupils learn, some were strong in practical work while others were good at academic knowledge. Her pupils used laptops connected to the internet where they search freely and found appropriate materials. The projector is useful for teaching science in her view, "both when one is showing different pictures and other things one finds on the net, what one doesn't find in books." She used the internet to find answers to questions she didn't have ready answered to and advised pupils to do the same. Pupils used projectors to project selected pictures and drawings from the internet when making posters, among other things. Describing herself as a science teacher, Lin said: "Like somebody who makes sure that things work, but not necessarily as someone who gives orders on what to do."

It wasn't easy to analyze the roles of Jacob's pupils when it came to ICT, as it wasn't clear how and when such technology was directly used in the learning. Perhaps his pupils were first and foremost explorers but at the same time creators and receivers. Jacob had good command of the content knowledge in all fields of science, as he had solid education in that area. He said it was important that pupils understood what they were doing and conversations and discussions were particularly important in that regard. He made a conscious effort to talk to his pupils both within and outside school hours both directly, and also through msn and email. Sometimes the discussion revolved around ethical issues and even confidential issues which were related to the subject. He spoke of the importance of critical thinking and related it to life skills more generally. From what he said it could be inferred that he avoided making pupils the receivers the knowledge: "I don't just stuff them with knowledge, I also take and let themselves digest things and assist them and guide them from the sidelines". He felt that were differences between the genders in this regards, the girls were keener on getting the materials directly than the boys.

Simon's teaching practices aimed at the same time for students to become receivers of information and data with the assistance if ICT, explorers of ideas and information and creators if materials presented in a novel way. At the same time they were revisers because they analyzed data and revised it using various methods, he made extensive use of the internet as a source of information. The pupils themselves explored on the internet, they analyzed information and made presentations and they collected data. He would typically put forward problems and questions to be solved: "… but most often one has to come up with something that has to solve you see. I'd have liked to use the lego for the forces very much you see, if I had been teaching it. Then they have made vehicles', raised the vehicles and such things and then have to measure speed and distances and make a speed/distance diagram. And it sticks better, that is concepts and units, that is to work things like this". Simon's plans were interesting:

> Yes, I dream about making an information hub where they in their own way express themselves about concepts…and then we car, you see, go to that source and make something smart out of the whole thing… And in science with me I make the usually hand in typed rather than handwritten. And there as they learn, you see, to set up things in word, figures and illustrations and all that (from an interview 3.19.005)

Summary and discussion

This paper reports into how a study of how five Icelandic science teachers used ICT in their teaching. The use of digital technology turned out to be variable among participants, all from communicating through MSN and email to well thought programming using techno-lego. The view and the value of ICT in learning and teaching also turned out to be varied, and also applied to teaching practices in general. But in spite of all their differences it was interesting to observe what important possibilities for using ICT in science did not seemed to be used much among the five teacher, e.g. recording, analyzing and interpreting data, with the aid of a spreadsheet, use of digital measuring equipment e.g. scales and thermometers, and the used of models. Finally it was note worthy how different the teachers seemed to be as well as the atmosphere of those five schools.

Bennett (2003) concluded that the use of ICT in science teaching and learning mainly dependent on professional decisions of teachers and their attitudes i.e. professional theory. The concept of professional theory refers to the ideas which guide direct actions of teachers in their work (Bjarnadóttir, 1993). The ideas and decisions on these matters are both professional and personal because they are influenced by the knowledge and experience the teacher has gained during his education and work and they also depend on the teachers' personal characteristics, views on life, attitudes and values. It appears that professional theory influenced the decisions of the five teachers more than the special characteristics of the subject and the associated area (cf. *subject-specific practice*). For instance their views on their positions and responsibilities towards the pupils differed, from seeing it as their main role to transmit knowledge and making their pupils stick to the study materials to "speculating about this with them" one can take detours, as Simon phrased it, and in this way take into consideration the differences among the pupils. In him, and actually with regards to Lin as well, we could however see signs of commitment to the subject and its nature not only because of how they applied teaching practices which characterized practices and skills in science but also in the extent to which they used the opportunities of ICT.

These two things, changing professional view and the apparent under-usage of the possibilities of ICT, undeniably indicates that science teachers need increased support, both from within and from outside their environment. But as Bennett (2003) has pointed out, classical continuing education courses are not enough. A new forum for teachers must be created to form a society around methods and teaching practices (see also OECD/CERI 2008, 2009), which is also exactly what Saga and Jacob mentioned in their interviews. Solid support from the near environment is important as well, also flexibility for inner planning and access to appropriate equipment where education takes place, it is not enough to have access to a specially equipped computer classroom. An important conclusion reached by Bennett is that good access to ICT for the gathering, measuring, and recording of data (*data logging*) and modeling, (e.g. *simulations*), can make all the difference because it can save time in working with data and give more flexibility for discussion and interpretation of what stands out as important in the education process. This is also in agreement with studies on education as a process and the emphasis on work practices and methods (cf. Baggott La Velle and co-workers (2003).

The importance of ICT in the learning and teaching of science

It is clear that the use of ICT and the time and space allocated to it varies among the five science teachers. Three of them i.e. Peter, Saga and Jacob do not appear to emphasise the use of digital technology in learning, at least not to the extent the national curriculum appears to expect. The other two use the technology quite a bit, in particular Simon. Perhaps this tentative approach has similar explanations as Peter John (2005) put forward in the study mentioned earlier. Subject teachers have found to be willing to make space for ICT in their teaching, as long as the technology did not revolutionize the foundations of the subject in question. Undeniably the structure and application possibilities of the media (ICT) have considerable influence on the content and organization of the teaching which increases with increased emphasis on ICT. Understandably science teachers are faced with difficult choices when it comes to ICT, not least if he or she feels that they do not have adequate knowledge of the possibilities and influence of the technology. Saga, for instance, said that she had felt her way with different use of ICT but that she had not mastered it: “The internet isn’t of great use because I don’t know how to make use of it…or it is so slow.” Finally, all five teachers agreed that the goals of national curriculum and the national exams hindered that teaching practices based on the use of ICT got the flexibility that would have been desirable. Hennessy et. al. 2005 reached a similar conclusion in their study.

The purpose of using ICT cf. Twinings’ CPF model

Twining (2002) used his CPF model to analyze amongst others three types of digital technology. When it was a question of support ICT did not make much difference to the contents and methods, but offered faster and even more efficient methods of learning and teaching. All

participants in the study used ICT in this way, either through the use of power-point, word-processing programs or other software though perhaps Jacob used it the least. Twining argued that an extension or addition would bring about some changes in the content and methods of learning and teaching, for instance through the use of the internet. Targeted use in this way was observed in two of the teachers, and to some extent with the third. Both Lin and Simon said they gave their pupils exercises where they especially had to use ICT.
Transformation according to the CPF model is when there is a change in the content and/or methods of learning and teaching. In this case there would be goals that could not be obtained without the use of ICT. Studies, which have been discusses earlier, and also our own experience show that the use of ICT as a support and addition appears fairly general in school work. This seems to be a permanent systemic change in the work of school and other societal institutions. Word processing is for instance often used for various purposed and programs to transmit information for instance power-point is widely used, in addition to other software and media, not to forget the internet itself. The use of digital technology to bring about changes in learning and teaching however, is not easy to find in schools. The explanations are undoubtedly to be found in different traditions in relation to organization of school work. Tyack and Kuban (1995, p.124) described the mainstream view on the organizational structure of schools as the main hindrance for computer equipment to become a part of that structure and mentioned in particular "classroom organization", and "the institutional structure of the school" and how "teachers define their role and tasks".

Peter John (1995) found that subject teachers showed a certain resistance to ICT, even suspicion: John compared ICT amongst others to a "Trojan horse" in this connection. Teachers however appeared to increasingly make use of computer technology within their subjects but most often linked to clearly defined goals, the content and nature of the subject. Most examples of the role of ICT in our study support this. In one place Saga, for instance, said she thought it would not be sensible to give students a free reign with the computer to search for problems or games in physics: "I will do it, but what will the others do?... It is no good to give them that sort of assignment, I wouldn't do it…". Jacob and Simon both said they assumed that their pupils used ICT in working on project, reports and presentations. But in most cases by far it was a question of support and addition (c.f. Twinings' CFP model) to the content and goal of the subject, rarely a bold change on the content or methods. It can though be said that Simon's work in lego technology was an exception. His ideas about a computer run model of the solar system and to have pupils in role of authors of science-based materials are also interesting in this light.

Procedural knowledge

At the time of the study the national curriculum from 1999 was in force with the exact and detailed goals aimed at different stages of schooling and also an annual exam in science for the 10th grade. Teachers felt therefore a certain conflict because of the demand to cover all the material on the one hand and the will, on the other, to take time to do practical exercises and observations with pupils: "…unfortunately the national exam means that you can not make them do experiments, especially since we went on strike… we have to cover the text, that is number one." (from an interview with Saga).

Whatever the case might be the national curriculum in effect at that time (1999a) did make it clear that each pupil should:

> Should be able to carry out varied observations and use measuring tools and appropriate equipment. To be able with increased independence gather information on a certain topic through different means (among others) through computer communication…to be able to record events and observations in a certain and clear way using a computer… be able to evaluate the reliability of references and information by using the internet… to be able to present the result of their observations in a clear and concise way using a computer and other electronic media. (Ministry of Education 1999a, p.44-46).

According to the goals for the 10th grade it was also assumed that students would be able to "work independently on the analysis of data and among others make use of the possibilities offered by various programs, spreadsheets, simulators" (Ministry for Education 1999a p.66, presentation slightly altered).

The need for training in independent work procedures and skills in the activities described here is clearly in place judging by our results. The interviewees gave examples from their teaching when pupils did not seem to be "connected" when doing independent work. Saga's story was for instance particularly interesting, about pupils who read 2 degree Celcius on a thermometer instead of 20 degrees Celcius but did not connect it with the temperature they felt in their environment. It also appears to worry both Jacob and Peter how dependent the pupils prove to be when they had to do something on their own, e.g. experiments or practical assignments: "…they lost themselves in what they were doing, it sometimes feels that they do not know exactly what they are doing" (from an interview with Jacob).

Bennett (2003) highlights two important items in this connection from research in science education. Firstly that independent work on assignments by pupils give better results if put into a real context which children and youth know and are interested in (*context-based approaches*). Secondly she refers to studies on the ideas pupils have on scientific problems and natural phenomena, which show that there are explanations are rarely at odds with the accepted ideas and explanations of scientists. Bennett summarizes recommendations for researches on learning and teaching and its connection. There are two items that are of prime importance. Firstly we consider it a key issue that the teachers elicit pre-ideas and knowledge of pupils for instance by targeted discussion which was so notable in Jacobs teaching. Then it would be ideal to give the pupils problems or an assignment of some sort which (challenged) the pre-ideas in some way. In this regard ICT could be involved in some way.

From the above one could conclude that procedural knowledge is an important part of science education and that in this regard ICT can be used in different ways, when things are done properly. National exams, covering materials, the fact that “pupils don’t know what they are doing” or “pupils don’t connect” are not convincing arguments against such teaching practices in science. As teachers we cannot learn for the pupils. The battle is theirs. It is a pre-requisite for learning.

The role of pupils

In one place Lin noted that pupils learned in different ways. Some were more comfortable with practical work while others felt better with academic studies. Another side to such a discussion is without doubt the question if independent work and an enquiring mind suits some pupils better but that others prefer clear directions on what should be learned and what has to be done to get results. Jacob feels that there is a difference between boys and girls in this regard, the boys are more practical while the girls prefer academic learning. That debate is also influenced by the attitudes of teachers and pupils towards studies and the philosophical base of education such attitudes reflect. Apart from what the ideology is it has to be a key issue to realize in what way the activity of pupils appear in the study process. Researchers saw Aðalstein’s pupils primarily as receivers, not as explorers, creators, or revisers, cf. the research of Newton and Rogers (2003). But most of the 26 pupils that were observed in Aðalstein’s lesson on heat transfer seemed without doubt to be active and learning certainly took place. In the lesson observed when Simon was teaching pupils were primarily in the roles of creators and revisers. Pupils had selected an element from the periodic table to independently collect information about and present their findings to their classmates. The activity of some could be doubted but those presenting and listening. Jacob emphasized chat and discussions, as it guaranteed that the main goal of the study i.e., that pupils understood what they were doing. On the other hand, Saga said she was not very ‘adapt’ in such teaching practices in general and therefore she gave the pupils more of a free reign, even so she said she supported such work practices and therefore called for support or courses in these matters.

Methods for learning and teaching can thus be expressed in many ways and also the role of teachers on the one hand and the pupils on the other. The interaction between students and teachers in the study process is complex and it is certainly difficult to realize what is really going on in a small study such as this one. It is clear however that the role of the teacher and his professional theory are of prime importance according to these results. There general attitudes, knowledge, prior experience and last but not least professional view are important. Some of the participants in the study proved to have a good command on the subject content, others a good command on pedagogical factor and others still on the possibilities of teaching material and equipment, for instance those who are connected to ICT. All of this matters. But according to the data presented here the researchers think it is most important to look towards what Shulman (1987) called "pedagogical content knowledge" (*PCK*), i.e. in what way this knowledge comes together in a coherent whole and makes the science teacher into the type of professional thought to be desirable. There the content of subjects and some extent those disciplines upon which they are based (physic, chemistry, biology etc.) knowledge of theories about learning and teaching, varied teaching methods, appropriate equipment and environment of study and last but not least an insight into research on education and what it tells us about the changing role and premises of pupils, their motivation, self-image and preconceived-ideas.

Conclusion

The main result of this research is that each science teacher seems to be guided by his/her own theory which is clearly determined by the knowledge and experience each has gained in his/her studies and work. According to the study, one can assume that the professional theory of each of the five teachers influenced more the use of ICT and thereby their view on ICT, and the special characteristics of the subject and the culture or tradition which goes with it (cf. subject-specific practice). From this it follows that the goals that come under "work practices and skills" and "role and nature of science" according to the national curriculum 1999 seemed to be weak and unclear in the teaching practices of the five teachers. Research into use of ICT in science education, and actually also remarks made by participants in this study support the need for targeted support for the development of such teaching practices and better access to equipment and data than is the case (cf. Bennett's 2003 review, see also Shulman 1987). It is not enough to set a public policy in the national curriculum one also needs a realistic strategic plan inside and outside the school and a good support to the community of subject teachers in this field.

APPENDIX III

RCE DATA

Practitioner-Researcher Sources of Data – RCE

This research is to a considerable extent an insider investigation, entailing that the data is partly what has been labelled as ‘practitioner-researcher data’. To underpin the main findings and reflect on data filtered out of text analysis, interviews, and on-site observations I used important data from my work as an educational advisor for Reykjavík Centre of Education (i. *Fræðslumiðstöð Reykjavíkur*), RCE, at the end of the last century and from my participation in the Intentions and Reality Study (IR) (See Appendix IV).

RCE Sources of Data Based Upon:

Minutes from a meeting about the status of school science education in Reykjavík, in December 12th 1997. The meeting was held at the RCE and was attended by 25 representatives from the Icelandic Teacher Union, The Iceland University of Education, The Faculty of Science of the University of Iceland, curriculum developers from The Ministry of Education, The National Centre of Educational Materials and RCE. Minutes from the meeting cited as **RCE-I** in text.

Þórólfsson, M. & Birgisdóttir, F. (1998). *Staða eðlis- og efnafræðikennslu í grunnskólum Reykjavíkur haustið 1997. Niðurstöður könnunar sem lögð var fyrir fagstjóra og árgangastjóra* [The status of physics and chemistry instruction in Reykjavík´s compulsory schools in autumn 1997. Results from a survey sent to professional leaders in school science]. Reykjavík: Fræðslumiðstöð Reykjavíkur. Also in reference list. **RCE-II**.

ECS. (2002). *Lokaskýrsla vegna móðurskólaverkefnis 1999–2002*. [Final report from East Comprehensive School (ECS) about the Model school project 1999–2002] issued in 2002, but not formally published. Cited as **RCE-III** in text.

WES. (2007). Interview with two teachers from West Elementary School (WES). Cited as **RCE-IV** in text.

ECS. (2007). An interview with one teacher from East Comprehensive School (ECS). Cited as **RCE-V** in text.

New years greeting presented by the principal of SES on the Internet on January 17, 2001. Cited as **RCE-VI** in text.

Other informal sources of data such as minutes, memos, and other file from my work as a practitioner in education in 1995 – 2007. Cited as **RCE-VII**.

APPENDIX IV

IR DATA

Practitioner-Researcher Sources of Data – IR

As indicated in Appendix III the data used in this thesis is partly labelled as 'practitioner-researcher data'. In addition to data from my work as an educational advisor for Reykjavík Centre of Education I also applied data from my participation in the Intentions and Reality Study (IR) to underpin the main findings from text analysis, interviews, and on-site observations.

The *Intentions and Reality* (*IR*) project (i. *Vilji og veruleiki*) was an opportunity to focus further on the implementation and influences of new law 1995, the new national curriculum 1999 and reintroduction of the centralised examination in 2002. It comprised collecting data in 2006 and 2007 on education in science, technology and innovation education from schools in five different areas of Iceland, the rural east, the coastal east, the rural/coastal west, the peri-urban southwest and the capital city.

My participation included translation of the Icelandic version (ISCIQ) of the *Science Curriculum Implementation Questionnaire* (SCIQ), based on Dr. Brian Lewthwaite's doctoral research (Lewthwaite, 2003), which was developed to gather quantitative data about the teachers' views on five factors in school science. In addition to circulating the questionnaire to the participating schools I visted 10 schools with other researchers and took part in writing seven reports on these visits. The visits included the collection of interview data from principals, teachers and pupils in lower-secondary grades, as well as on-site observations, classroom observations and assessments of teaching conditions.

IR Sources of Data Based Upon:

Macdonald, M. A., Pálsdóttir, A., & Stefánsson, K. K. (2008). Intentions and reality: science and technology education in Iceland. Final report submitted to the Research Fund of Iceland. Retrieved Jan 20, 2012, from http://mennta.hi.is/starfsfolk/kristjan/vv/. Cited as **IR-I** in text.

Macdonald, M. A., & Þórólfsson, M. (2006). *Náttúrufræðimenntun á Austurlandi. Haust 2006. Grunnskólinn Egilsstöðum og Eiðum.* [Science Education in East Iceland. Autumn 2006. Egilsstaðir & Eiðar Comprehensive School]. Cited as **IR-II** in text.

Stefánsson K. K., & Þórólfsson, M. (2006). *Náttúrufræðimenntun á Austurlandi. Haust 2006. Nesskóli.* [Science Education in East Iceland. Autumn 2006. Nes Comprehensive School]. Cited as **IR-III** in text.

Þórólfsson, M., & Jónsdóttir, S. R. (2006). *Náttúrufræðimenntun á Austurlandi. Haust 2006. Grunnskóli Eskifjarðar.* [Science Education in East Iceland. Autumn 2006. Eskifjörður Comprehensive School]. Cited as **IR-IV** in text.

Pálsdóttir, A., Pétursdóttir, B., & Þórólfsson, M. (2006). *Náttúrufræðimenntun á Austurlandi. Haust 2006. Menntaskólinn á Egilsstöðum*. [Science Education in East Iceland. Autumn 2006. Egilsstaðir Secondary School]. Cited as **IR-V** in text.

Lárusson, E., & Kristinsdóttir, E., Stefánsson, K. K., Þórólfsson, M., Bergmann, S. & Jónsdóttir, S. R., (2006). *Náttúrufræðimenntun á Snæfellsnesi. Vor 2007. Grunnskóli Snæfellsbæjar*. [Science Education in West Iceland. Spring 2007. Snæfellsbær Comprehensive School]. Cited as **IR-VI** in text.

Other informal sources of data from my work in IR 2006 – 2007. Cited as **IR-VII**.