L3) Physical Sciences Education. By Dr Robert Rose

In this lecture, we want to look at Steiner's philosophy of the physical sciences education. The physical sciences in Steiner settings include the traditional subjects of physics and chemistry as well as others. This lecture does not include the *specific* content of the curriculum as such, but involves a consideration of the *generic* **content** of the curriculum as well as the teaching methodology, i.e. the **pedagogy** and the **research method** specific to the physical sciences.

As a formal subject, in Steiner / Waldorf Schools the physical sciences are not taught before the child's 12th year, that is, at the beginning of the third sub-phase of child development (see module 3). Shortly, we will consider the developmental reasons for this, but for now it is thought that this is the optimal time to introduce this subject to help the development of the children. As we will see, the methodology for the physical sciences is often referred to as "phenomenological". We introduced this in module 2, L4, which you might like to re-read at this point. Moreover, the traditional distinction between physics and chemistry is questioned by Steiner as he sees them as a unity and should be taught as such. This is due to his view that they should be interpreted as two aspects of the "inorganic world". We will also consider here Steiner's holism in this field and the practical implications for the physical sciences curriculum.

For the further study for this module it would be good to read: Avison, K & Rawson, M (eds) (2014): *The Educational Tasks and Content of the Steiner Waldorf Curriculum*, Floris Books:

1) Physics: Chapter 23, Physics.

2) Chemistry: Chapter 11, Chemistry

Child Development in the third Sub-Phase: the emergence of the Physical Sciences

As mentioned, the physical science curriculum does not begin until the child's 12th year, in class 6. Steiner explains:

"We should not speak to children of inanimate things at all before they approach the twelfth year. Only then should we begin to speak about minerals, physical phenomena, chemical phenomena, and so on. We must make it clear to ourselves that this is really how things are: in the child between the change of teeth and puberty it is not the intellect but the fantasy that is predominantly active; we must constantly be thinking of the child's fantasy, and therefore, as I have often said, we must especially develop fantasy in ourselves. If we do not do this, but pass over to all kinds of intellectual things when the children are still quite young, then they cannot go through their development rightly even in their physical body. **And much that is *pathological* today arises from the fact that in this materialistic age too much attention has been paid to children's intellect between the change of teeth and puberty**. Steiner, R (1924): The Kingdom of Childhood, Anthroposophic Press, p. 110. (My bold and italics)

As we saw in module 3, the young person, according to Steiner, only has the first inklings of intellectual development in the 12th year, even then not properly until they are around 14. For him, the introduction of subjects whose **inherent** nature is "intellectual" should therefore not be central until this time.

As we have also seen before, Steiner was of the view that particular subjects represent specific ways of learning, knowing, and thinking. In this context, mineralogy, physics and chemistry represent an approach grounded in the human capacity of the **intellect** (as distinct from imagination, reason, intuition, etc). Consequently, in order to adapt the learning process to the development of the child, the inorganic sciences ***per se*** should only be begun to be taught at the appropriate ontogenetic point, that is in the 12th year (cf module 3). This is not to say that the inorganic subjects cannot be taught prior to this time, only that the **inherent** mode of understanding and learning (of these types of subjects) should not be taught:

"Until the **end of the ninth year**, everything children learn about plants, animals, and stones, about the sun, moon, and stars, or about clouds, mountains, and rivers should be clothed in pictures, **because children will feel at one with the world**. In those young days, a child and the world are one whole." Steiner, R (1921): Soul Economy, Anthroposophic Press, pp 161-63. (My Bold)

As we have seen many times before, all subjects can be taught from class 1 onwards, provided that they are introduced through imaginative anthropomorphisms (sub-phase 1) or through imaginative pictures (sub-phase 2). It is only in sub-phase 3 that a more conceptual approach may be begun, even then over-shone by imaginative learning:

"In our work with children of elementary school age we must see to it that we engage the rhythmic system only. The rhythmic system never tires, and is not overexerted when we employ it in the right way, and for this rhythmic system we need not an intellectual but rather a **pictorial method of presentation**, something that comes out of the **fantasy**. Therefore it is imperative that fantasy should hold sway in the school. This must still be so **even in the last period of which we have spoken**, from **eleven-and-two-thirds to fourteen years**; we must still **bring lifeless things to life through fantasy** and always **connect them with real life**. It is possible to connect all the phenomena of physics with real life, but we ourselves must have fantasy in order to do it. This is absolutely necessary." Steiner, R (1924): The Kingdom of Childhood, Anthroposophic Press, p. 114. (My bold)

As can be seen from this, even the inception of a more intellectual approach in the 12th year is modified or "brought to life" though fantasy. Simultaneously, the connection to real life has to be maintained for at least two reasons: firstly to stop the inorganic science curriculum becoming too abstract; secondly so that the fantasy life does not take over and make the curriculum divorced from it scientific content.

There is a inner physical side also to Steiner's argument:

"Because of all this, we harm their development if we teach children mineralogy, physics, chemistry, or mechanics in a way that is too intellectual for children before the eleventh year, because they do not yet have a corresponding experience of their inner mechanical and dynamic nature. Nor can children inwardly participate in the causal relationships in history before their eleventh year... On the other hand, if we teach children about the principle of levers or the steam engine before they reach eleven, they cannot experience this inwardly, because the dynamic of their own physical nature has not yet developed. **If we begin physics, mechanics, and dynamics at the right time (when children are about eleven or twelve), whatever we present in thinking goes into the head and is met by what comes from their inner being—the experience of their own skeletal system**. What we say to them unites with the impulse and experience that arises from the body. Thus a soul understanding arises instead of an abstract, intellectual understanding. This must be our goal". Steiner, R (1922): The Spiritual Ground of Education, Anthroposophic Press , p. 80/81.

For Steiner, the introduction of the physical sciences curriculum in the 12th year mirrors the physical development of the children. According to Steiner, the human skeleton system develops significantly at this time, consequently, the physical sciences, with their inherent inorganic mode of thinking, can be introduced as a reflection of what is occurring within the physical body.

The Content of the Physical Sciences Curriculum

Additionally, as the nature of "matter" (and energy) is normally considered to be a part of the central concerns of physical sciences education, Steiner thought it important to address what the goal of learning should be in this context. Using chemistry as an example he argues:

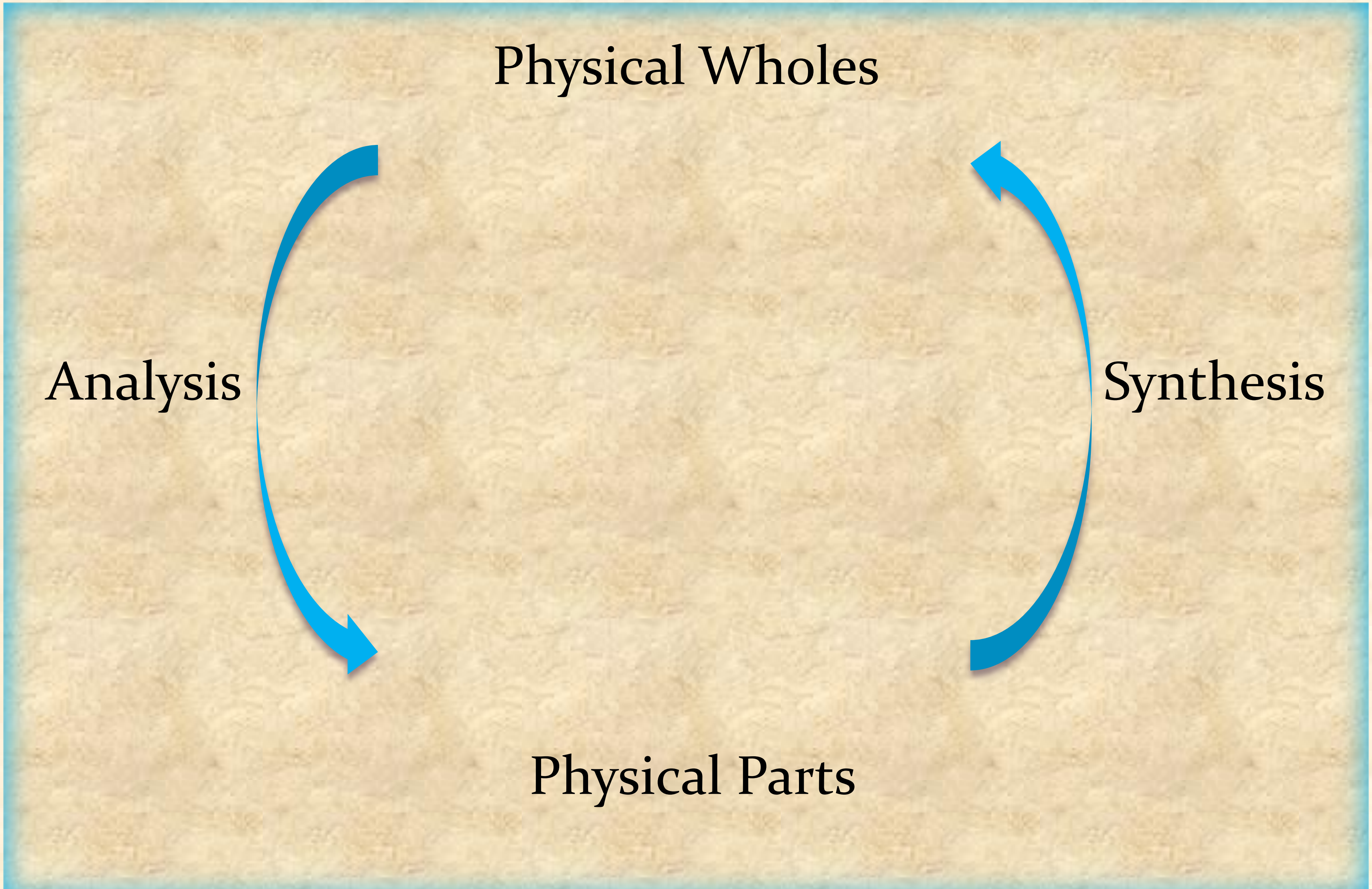
"In chemistry… I believe that is what we should include in a survey of matter. I do not believe it is correct to develop chemistry on the basis of matter. It is better to develop the process and then bring in matter and metals so that during the instruction a feeling arises that **matter is simply a static process**. The children should have a picture of matter as simply a static process. If you have a piece of sulphur in front of you, what you really have is a static process. If I am standing here, and it is raining hard, then I have a process in which I am included. However, if I look at the cloud from a distance, it appears as an object to me. When I look at certain processes it is as though I were standing in the rain, when I look at sulphur, it is as though I were observing the cloud from a distance. Matter is simply processes that appears petrified. Steiner, R (1919-22): Faculty Meetings with Rudolf Steiner, Anthroposophic Press, p. 360. (My bold)(My editing: the word "material" has been changed to "matter" as this represents the intended idea more clearly for this context)

For Steiner, chemistry is more than just about **matter**, it is about **process**. For him, matter is an outcome of a process, or a process that has become static, or frozen. So ***process*** should take priority in the teaching of chemistry to help the children see that chemicals are outcomes of a process rather than fixed things that make other things happen. Similar arguments can be made with regard to the contents of physics with the inclusion of energy. After all, in physics the process of the transformation of one kind of energy into another is well known under the umbrella of the "Law of Conservation of Energy". If you are interested in this topic, see exercise 1 near the end of this power point.

In terms of an approach to the physical sciences curriculum, the teacher is tasked with finding examples from the natural world or from modern life through which this process can be demonstrated. So, rather than starting with atomic or sub-atomic models through which matter is supposedly explained, the intention would be to show a **phenomenological *process*** of how physical matter or energy arises. In this, children are given a sense of engagement and discovery in the physical sciences; this is instead of being delivered an end result to which they have to adhere or fit into.

Between the Wholes and the Parts: From Analysis to Synthesis in the Physical Science Curriculum

Included in understanding this process in physical **reality** is a process in **methodology**. In module 5, L1c, we introduced the generic idea that the Steiner / Waldorf curriculum can be understood as involving a methodological process from the Whole to the Parts and back again; a process of analysis and synthesis. This principle, as we have seen many times, is true of any subject. In the context here, we want to explore what this would mean for the physical science curriculum, for example, for physics and chemistry. This not only has methodological implications, but also the choices that are made in terms of fields to be covered and objects and processes to be studied. The key question concerns the physical wholes that are chosen for educational purposes from out of which the parts are analysed and then synthesised through the pedagogy. The next slide represents the generic process:


Physical Wholes
Analysis
Synthesis
Physical Parts

Physics and Chemistry as an Organic Unity

One example of Steiner's holism in this area is that he intended physics and chemistry to be taught as one whole subject. For him, they were examples of what he called "inorganic science" (see module 2). His recommendations were that, wherever possible, the teacher should try to transcend the traditional separation of the two:

"In physics and chemistry, we should try to cover **every principle** that reveals the **whole system** of **chemistry and physics as an organism, a unity**, and not simply an aggregate as most people assume." Steiner, R (1919-24): Faculty Meetings with Rudolf Steiner, Anthroposophic Press , p. 608. (My bold)

This holism of the physical sciences may be perceived as quite a challenge to some as it requires a transformation of what we all have conventionally learned in our own education. At the same time, Steiner did not specify exactly how this should be done. This has the advantage of giving greater freedom to teachers in how they implement this goal. We will consider the whole system aspect later, but for now one way of approaching this would be to seek out examples where the physical and the chemical were two aspects of one object of technology or process of nature. We will consider this at a number of points in the following.

The Physical Sciences: Beginning with Real Life

As a starting point for this "Unity" or "Wholeness", Steiner recommended taking a ***real*** **whole** object, either from nature or from technology. He advised that the physical sciences curriculum should always be taught beginning with real life:

"For physical phenomena also it is just as important to start from life itself. You should not begin your teaching of physics as set forth in the textbooks of today, but simply by **lighting a match *for instance*** and letting the children observe how it begins to burn; you must draw their attention to all the details, what the flame looks like, what it is like outside, what it is like further in, and how a black spot, a little black cap is left when you blow out the flame; and when you have done this, begin to explain how the fire in the match came about. The fire came about through the generation of warmth, and so on. Thus you must connect everything with life itself…

Or take the example of a **lever**: do not begin by saying that a lever consists of a supported beam at the one end of which there is a force, and at the other end another force, as one so often finds in the physics books. You should start from a **pair of scales**; let the child imagine that you are going to some shop where things are being weighed out, and from this pass on to **equilibrium** and **balance**, and to the conception of **weight** and **gravity**. Always develop your physics from life itself, and also your chemical phenomena. **That is the essential thing, to begin with real life in considering the different phenomena of the physical and mineral world**. If you do it the other way, beginning with an abstraction, then something very curious happens to the children; the lesson itself soon makes them tired. The children do not get tired if you start from real life, they get tired if you start from abstractions."

Steiner, R (1924): The Kingdom of Childhood, Anthroposophic Press, p. 111/2. (My bold and italics)

Of course, this leaves open the question as to what is meant by "real life" and to what extent it differs to today. This is important to consider as what you might chose to present to the children as a teacher today might differ from how it might have been done in Steiner's time. He gives the following example that is still relevant in the contemporary World:

"Just think how many people today travel by electric train without having the faintest idea how an **electric train** is set in motion. Imagine even how many people see a steam engine rushing by without having any clue as to the workings of physics and mechanics that propel it. Consider what position such ignorance puts us in with regard to our relationship with our environment, that very environment we use for our convenience. We live in a world that has been brought about by human beings, that has been formed by human thoughts, that we use and know nothing about. **The fact that we understand nothing about something that has been formed by human beings and is fundamentally the result of human thinking is greatly significant for the whole mood of soul and spirit of humankind**. Human beings literally have to turn a deaf ear in order not to perceive the resulting effects." Steiner, R (1919): Practical Advice to Teachers, Anthroposophic Press, p. 154/5. (My bold)

The most important point about this concerns the pedagogical significance of the physical sciences curriculum. In particular, that we need to educate people so that they can be conscious of the creations of technology around them and how these affect society.

In the context of education, this indicates that the teaching of this subject should, as its starting point, introduce children, in an age appropriate way, to how the physical sciences manifest in the modern World. As stated, this may mean that the choice of what to teach may be different today, at least to a degree, than in Steiner's day.

Taking another example and recalling our earlier quote:

"Or take the example of a lever: do not begin by saying that a **lever** consists of a supported beam at the one end of which there is a force, and at the other end another force, as one so often finds in the physics books. You should start from a pair of **scales**; let the child imagine that you are going to some shop where things are being **weighed** out, and from this pass on to **equilibrium** and **balance**, and to the conception of **weight** and **gravity**. Always develop your physics from life itself, and also your chemical phenomena". Steiner, R (1924): The Kingdom of Childhood, Anthroposophic Press, p. 111/2. (My bold)

In this particular instance, the starting point is a whole object, namely a pair of scales, rather than an abstract concept such as gravity or weight. We have an example here of Steiner's holism and it is a holism of life. Steiner's approach is such that it is reality that should be the starting point for teaching, not an abstracted end point. The pedagogical process begins with a real life whole object and then proceeds to the parts, in this case abstract concepts such as weight and gravity are the **end** points of a pedagogical process that **begins** with a real life pair of scales. Of course, the teacher will have to proceed very concretely with other phenomena which can eventually lead to the abstract concepts of weight and gravity, such as falling objects and the weight of a person. In this way, the analysis moves back towards a synthesis.

In the example of the match, again we have a whole object. The parts of the match and situation can be analysed out: the wood, the chemicals on the end; the striking of the match and the generation of heat; the history of the making of the match, etc. From this, an "expanding picture for consciousness" can be produced for teaching which includes both physics and chemistry.

The electric train mentioned by Steiner is another case in point. The pedagogical starting point is again the whole train. Analysing this into its component elements leads to the study of the energising of batteries (in some cases) which leads to a study of chemistry in context, how this is converted into electricity, magnetism, motion and the mechanics of this process. Today, one might use the electric car as an example. Alternatively, there may be an exploration of petrol or diesel driven vehicles. In any of these, the holistic connection between chemistry, electricity, magnetism and mechanics can be taught in a way appropriate to this age (12^{th} year to 14 years). In all these examples, the teaching process demonstrates to the children how, through the physical sciences, one can begin with the whole in relation to real life, proceed to analyse to discover the parts, then to ascend again to the whole being or object through synthesis.

Of course, this process of deriving the physical science curriculum from "real life" does not imply that this only be done with technological creations, but also from nature. In fact , a part of this curriculum involves showing the children the relationship between them. This may also include the way nature becomes transformed in technology and the environmental implications.

The Physical Sciences through the Classes

In approaching the physical science subjects we need to bear in mind the **Wholes to Parts relationships** within each area and as a whole. So when, for instance, asking about the whole to part relationship in magnetism, what is the whole and what is the part in this context? What is the process occurring between them? The same question can be asked between each of the sub-topics of the physical sciences, what are the connections between motion and magnetism, sound and electricity, etc.

In terms of timing, given that these topics are spread across about six weeks, how is the time to be allotted? The physical sciences curriculum is covered in about six weeks in each year from class 6 onwards. Of course different teachers may chose to vary this length of time. This amounts to around 60 hours of teaching to cover physics and chemistry in each year, which is commensurable with the combined physics and chemistry curriculum for key stage 3 in mainstream schools.

For class 6, Steiner's proposal was that the following topics be covered:

"Instruction in physics begins in the **sixth grade** and is linked to what the children have learned in music. We begin the study of physics by allowing **acoustics** to be born out of **music**. You should link **acoustics to music theory** and then go on to discuss the **physiology of the human larynx from the viewpoint of physics**. You cannot discuss the human eye yet, but you can discuss the larynx. Then, taking up only the most salient aspects, you go on to **optics** and **thermodynamics**. You should also introduce the basic concepts of **electricity and magnetism** now." Steiner, R (1919): Discussions with Teachers, Anthroposophic Press, p. 195. (My bold)

In class 6, the children are in the process of becoming 12 years old. It is around this time that they undergoing a growth spurt and as a part of this the voice begins to change reaching the point of "breaking" at around 14 years. This likely one of Steiner's reasons for introducing the acoustics theme partly through a consideration of the larynx: it is around this time (or shortly thereafter) that it grows considerably and leads to a deepening of the voice.

Obviously, the choice of how to do all of this will have to embody a good degree of pedagogical economy if these topics are to be covered in this relatively short space of time. We can represent the topics to be covered as follows:

Class 6 Physical Science Curriculum
Acoustics, Music and the human larynx (and ear?)
Optics
Thermodynamics (Heat)
Electricity and Magnetism

For class 7, Steiner envisaged an ***application*** and ***expansion*** of what was covered in class 6, which was largely physics, but also with the addition of chemistry:

"In the **seventh grade**… We also attempt to ***apply*** the concepts the children have acquired in the fields of **physics** and **chemistry** to developing a comprehensive view of some specific **commercial** or **industrial** processes. All this should be developed out of science, in connection with what we are teaching in physics, **chemistry**, and geography." Steiner, R (1919): Discussions with Teachers, Anthroposophic Press, p. 194. (My bold and italics)

"in the **seventh grade**, you ***expand*** on your studies of acoustics, thermodynamics, optics, electricity, and magnetism. Only then do you proceed to cover the most important basic concepts of mechanics—the lever, rollers, wheel and axle, pulleys, block and tackle, the inclined plane, the screw, and so on.

After that you start from an **everyday process** *such as* **combustion** and try to make the transition to simple concepts of **chemistry**. Steiner, R (1919): Discussions with Teachers, Anthroposophic Press, p. 195. (My bold and Italics).

In each case the question would be how work in a holistic way, from analysis through to synthesis, both in terms of the subjects taught as well as the objects chosen for study:

Class 7 Physical Science Curriculum
Application of Physics and Chemistry to industrial processes
Expand on acoustics, thermodynamics, optics, electricity, and magnetism
Mechanics
Chemistry of combustion and other basic chemistry.

Class 8 is a further ***expansion*** and ***enhancement*** of subjects covered previously, but then a ***progression*** to **hydraulics** and **aerodynamics:**

"In the **eighth grade** you review and expand upon what was done in the seventh and then proceed to the study of **hydraulics**, of the forces that work through water. You cover everything belonging to hydraulics—water pressure, buoyancy, Archimedes' principle… "In the **eighth grade** … Once again, you present a comprehensive picture of industrial and **commercial relationships** as they relate to **physics**, **chemistry**, and **geography**. If you build up your science lessons as we have just described, you will be able to make them incredibly lively and use them to awaken the **children's interest in everything present in the world and in the human being**." Steiner, R (1919): Discussions with Teachers, Anthroposophic Press, p. 195. (My bold and italics)

"You conclude your study of **physics**, so to speak, with **aerodynamics** - that is, the mechanics of **gases** — discussing everything related to **climatology**, **weather**, and **barometric** pressure.

You continue to develop simple concepts of **chemistry** so that the children also learn to grasp how industrial processes are related to chemical ones. In connection with **chemical** concepts, you also attempt to develop what needs to be said about the substances that build up **organic bodies** — **starch**, **sugar**, **protein**, and **fat**." Steiner, R (1919): Discussions with Teachers, Anthroposophic Press, p. 196, (My bold)

Later, Steiner developed the themes for class 8 physical science:

"*Dr. Steiner: In* ***eighth grade*** **optics**, *you should teach only about* refraction (lenses) and the spectrum. In teaching **thermodynamics**, teach only **melting** (thermometer), **boiling**, and the **sources of heat**. Then go into **magnetism** only briefly. In **electricity**, you will need to teach about static electricity. In **mechanics**, the lever and inclined plane; and in **aerodynamics**, the lifting forces and air pressure.

In **chemistry**, you should cover **burning** and how **substances *combine* and *separate***. In the seventh grade, you should discuss optics and magnetism in more detail than in the eighth grade. You also need to cover the mechanics of solid bodies." Steiner, R (1919-22):

Faculty Meetings with Rudolf Steiner, Anthroposophic Press, p.66. (My bold and italics)

We might add further quotes which was intended for class 9 and later, but which have implications for class 8:

"*Do the children have a clear* idea about the importance of **salts**, **bases**, and **acids**? Steiner, R (1919-22): Faculty Meetings with Rudolf Steiner, Anthroposophic Press, p. 269. (My bold)

"You need to have an **inorganic**, an **organic**, an **animal**, and a **human** chemistry. Some examples for children might be hydrochloric acid and pepsin, or blackthorn juice and ptyalin. Then they will get the picture. You could also use the metamorphosis of folic acid into oxalic acid. Steiner, R (1919-22): Faculty Meetings with Rudolf Steiner, Anthroposophic Press, p. 748. (My bold)

This lead us to a fairly comprehensive picture of the class 8 physical science curriculum:

Class 8 Physical Science Curriculum
Review and expand on class 7 topics
Physics and Chemistry of industrial and commercial relationships
Optics (Lenses, Refraction and the Spectrum)(and eye?)
Thermodynamics
Electricity and Magnetism
Mechanics
Hydraulics
Aerodynamics: Climatology and Weather
Chemistry of combustion; fundamentals of chemical combination and separation; chemistry of organic bodies; salts, bases and acids.

The Physical Sciences as a Unified Whole Organism

In the quote shown earlier, Steiner made the recommendation that the teacher should "cover **every principle** that reveals the **whole system** of **chemistry and physics as an organism, a unity**". What I want to do here is make some elementary steps in understanding this.

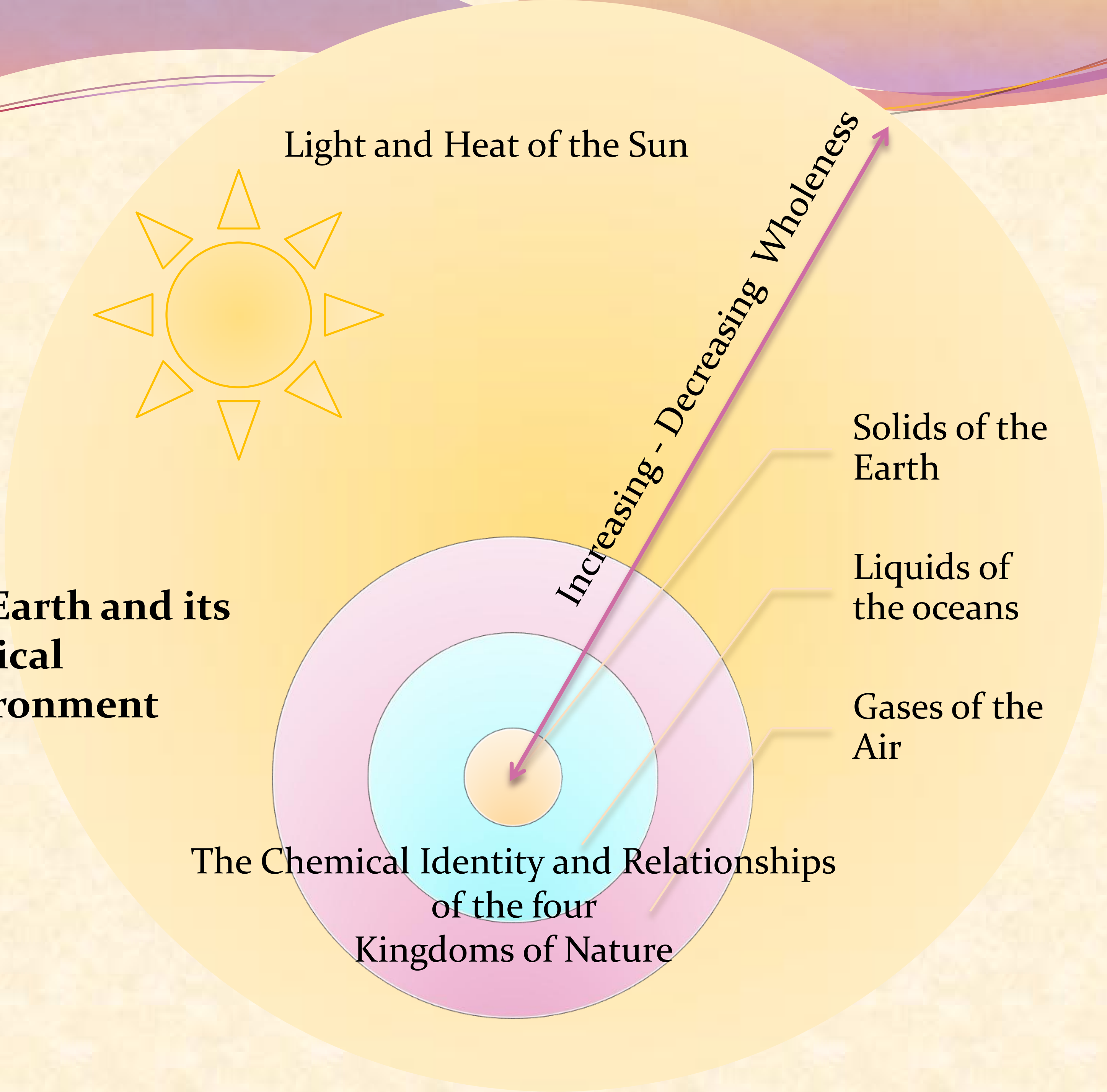
In the following slide, we have a list of the types of topics Steiner intended to be covered within the physical sciences curriculum. Just to note, the fact that there is only one row for chemistry does not imply that it should have any less attention than physics simply because there are seven rows for the latter. Additionally, as is known, in each topic there are a number of distinctive principles through which the phenomena of that topic are explained.

Rather than going through the physical sciences curriculum on a year by year basis, we want to consider the overall philosophy of the physical sciences curriculum across all the relevant years (classes 6 to 8). The subjects to be covered from a **holistic** perspective are:

Classes 6 – 8 Physical Science Curriculum	
Acoustics	Physics
Optics	
Thermodynamics	
Electricity and Magnetism	
Mechanics	
Hydraulics	
Aerodynamics	
Chemistry	

We might begin to represent these holistically in the following way :

The Earth and its Physical Environment



It is interesting to consider the above in relationship to the whole world and humanity as a ***starting*** point for treating the physical sciences as a unified organism (there is a good deal more that could be done here). Here we consider wholeness in the physical sciences with the **levels of wholes moving from above to below, from outside to inside (or the reverse).**

In **optics and thermodynamics**, we are of course introducing that form of physical reality that embraces the whole Earth, and also the whole solar system. Light and heat radiation are spherically emitted by the Sun and received by the Earth and enfolding it as a totality, enlightening and en-warming it in a complex number of ways. The introduction of the emission, transmission and reception of light and heat may form the basics of the optics and thermodynamics part of the curriculum (including heating and cooling, changes of state, conduction, convection and radiation). An introduction of the physics of human vision may form a part of the curriculum as might the physics of the human skin as a heat sensor.

In **aerodynamics**, we a dealing with the next layer of the Earth's embracement, namely that of the air. The air envelops the planet in a cloak that enables life to thrive. A study of its qualities enables an understanding of this all embracing element especially in relationship to forces and pressures of the climate and weather.

This also forms a link to **acoustics** in that, without the air, or some physical medium, no sound is possible. In this sense, in acoustics the physical ground of human and animal meaning, in speech and sound, is explored. From a holistic perspective, in music, the whole human being is a participant and from which acoustics is derived. The human being is the whole, acoustics is a part as are the larynx and ear a part of acoustics. From out of these basics, considerations of acoustic amplitude, frequency and the inverse square law may be made.

With **hydraulics**, the oceans, lakes and rivers provide the next layer of wholeness which can be studied through a consideration of the fluid element. The fluids flow around the whole planet and within all living creatures. Humans and animals drink it and plants draw in sustenance through it. An education in the flows, pressures and floating makes a step towards understanding this.

In **mechanics**, we have the solids of the Earth to consider. This is the foundation upon which the buildings of human civilisation are grounded. Even more so, the creation of tools is in the domain of solids, so a study of the mechanics of these enables an understanding of how humans have transformed the Earth. Force, torques, velocity, etc, come into the curriculum here.

In **electricity and magnetism**, we are dealing with really "deep Earth" properties in that the most dense of the solids come under consideration in respect of these properties: metals such as copper, aluminium and iron. In electricity, electrostatics is an option as are electrical circuits; in magnetism, electrical machines may be of interest, such as motors and generators, but also might be the emission of this deep Earth quality in relationship to the globe embracing magnetic field of the Earth.

In **chemistry**, we are dealing with the substance identity of the kingdoms of nature. Materials when placed near to each other, or within, or around, undergo changes, or processes, in different ways and degrees. There is something about the mere **identity** of these materials which enables these changes or transformations. In some cases, materials do very little when near each other, others undergo radical change or are even very active or violent. To the child, there is nothing obvious about chemical existence. We do not find free-floating chemicals around us, but whole "objects" which we adults think are "made" of materials. What we normally regard as an element or a compound arises from processes that change these whole objects into something else.

The totality of the process can be understood in terms of the polarity of the different types of separation and combination of substances. **Separation processes** include filtration, evaporation and distillation, chromatography and electrolysis. **Combination processes** can include simple baking but can also include high speed electron accelerators (not something an average Steiner School would have, nor would it be used at this age even if they did).

This approach stands in contradistinction to the mainstream way of doing chemistry. In standard chemistry teaching, children are frequently presented with a combination of the atomic model of matter together with the periodic table. Often, this is done **prior** to experimentation. These metaphysical models are then used as the explanation of observable phenomena. From out of these models, the elements and compounds are also explained as the base of all observable matter and through which all other forms of chemical combination are explained. From a Steiner Education perspective, however, the atomic view of matter and the chemical elements are themselves **outcomes** of a **process**, not entities that predetermine material processes.

This affects the ideal way chemistry teaching should be done in Steiner Education settings. To *begin* an main lesson block on chemistry requires not the presupposition of unobservable metaphysical models nor the fetching of a few flasks of chemicals from a cupboard and placing them in test tubes, for instance; but with real life objects which the children recognise from their lives. From out this a chemistry curriculum is devised.

From a **phenomenological** perspective, rather than a **metaphysical** one, when observing a given material, it is not obvious to the senses that it is composed of anything. Yet in traditional chemistry teaching, objects are said to be “made” of this or that chemical. But this is not a direct observation, it is a conclusion drawn from a series of experiments in which chemicals are either separated out from a whole entity or combined to form a new one: **what we call chemicals are outcomes of processes**. This is an idea that Steiner wanted teachers to understand and to convey, **in an age appropriate way**, to children. Another way of looking at this would be to interpret the physical world as being in a **continuous process of *separation* and *combination*** rather than as there being underlying fixed entities which determine the process.

An example of this is the periodic table. The periodic table arose through experiments based on processes of separation. The elements that make up the table are mostly not found directly in nature but through different kinds of separation process, such as electrolysis. Some elements, such as gold can be found in nature and which is fairly easily separated from its surrounds. Other elements are much harder to separate. Arguably, then, the following picture of the periodic table represents not so much an **underlying** reality but an outcome of a complex set of **processes**. It is this idea that Steiner thought important to form a part of the physical sciences curriculum:

PERIODIC TABLE OF ELEMENTS

1	Atomic Number
H	Symbol
Hydrogen	Name
Nonmetal	Chemical Group Block

1 H Hydrogen Nonmetal																	2 He Helium Noble Gas
3 Li Lithium Alkali Metal	4 Be Beryllium Alkaline Earth Metal											5 B Boron Metalloid	6 C Carbon Nonmetal	7 N Nitrogen Nonmetal	8 O Oxygen Nonmetal	9 F Fluorine Halogen	10 Ne Neon Noble Gas
11 Na Sodium Alkali Metal	12 Mg Magnesium Alkaline Earth Metal											13 Al Aluminum Post-Transition Metal	14 Si Silicon Metalloid	15 P Phosphorus Nonmetal	16 S Sulfur Nonmetal	17 Cl Chlorine Halogen	18 Ar Argon Noble Gas
19 K Potassium Alkali Metal	20 Ca Calcium Alkaline Earth Metal	21 Sc Scandium Transition Metal	22 Ti Titanium Transition Metal	23 V Vanadium Transition Metal	24 Cr Chromium Transition Metal	25 Mn Manganese Transition Metal	26 Fe Iron Transition Metal	27 Co Cobalt Transition Metal	28 Ni Nickel Transition Metal	29 Cu Copper Transition Metal	30 Zn Zinc Transition Metal	31 Ga Gallium Post-Transition Metal	32 Ge Germanium Metalloid	33 As Arsenic Metalloid	34 Se Selenium Nonmetal	35 Br Bromine Halogen	36 Kr Krypton Noble Gas
37 Rb Rubidium Alkali Metal	38 Sr Strontium Alkaline Earth Metal	39 Y Yttrium Transition Metal	40 Zr Zirconium Transition Metal	41 Nb Niobium Transition Metal	42 Mo Molybdenum Transition Metal	43 Tc Technetium Transition Metal	44 Ru Ruthenium Transition Metal	45 Rh Rhodium Transition Metal	46 Pd Palladium Transition Metal	47 Ag Silver Transition Metal	48 Cd Cadmium Transition Metal	49 In Indium Post-Transition Metal	50 Sn Tin Post-Transition Metal	51 Sb Antimony Metalloid	52 Te Tellurium Metalloid	53 I Iodine Halogen	54 Xe Xenon Noble Gas
55 Cs Cesium Alkali Metal	56 Ba Barium Alkaline Earth Metal	*	72 Hf Hafnium Transition Metal	73 Ta Tantalum Transition Metal	74 W Tungsten Transition Metal	75 Re Rhenium Transition Metal	76 Os Osmium Transition Metal	77 Ir Iridium Transition Metal	78 Pt Platinum Transition Metal	79 Au Gold Transition Metal	80 Hg Mercury Transition Metal	81 Tl Thallium Post-Transition Metal	82 Pb Lead Post-Transition Metal	83 Bi Bismuth Post-Transition Metal	84 Po Polonium Metalloid	85 At Astatine Halogen	86 Rn Radon Noble Gas
87 Fr Francium Alkali Metal	88 Ra Radium Alkaline Earth Metal	**	104 Rf Rutherfordium Transition Metal	105 Db Dubnium Transition Metal	106 Sg Seaborgium Transition Metal	107 Bh Bohrium Transition Metal	108 Hs Hassium Transition Metal	109 Mt Meitnerium Transition Metal	110 Ds Darmstadtium Transition Metal	111 Rg Roentgenium Transition Metal	112 Cn Copernicium Transition Metal	113 Nh Nihonium Post-Transition Metal	114 Fl Flerovium Post-Transition Metal	115 Mc Moscovium Post-Transition Metal	116 Lv Livermorium Post-Transition Metal	117 Ts Tennessine Halogen	118 Og Oganesson Noble Gas

*	57 La Lanthanum Lanthanide	58 Ce Cerium Lanthanide	59 Pr Praseodymium Lanthanide	60 Nd Neodymium Lanthanide	61 Pm Promethium Lanthanide	62 Sm Samarium Lanthanide	63 Eu Europium Lanthanide	64 Gd Gadolinium Lanthanide	65 Tb Terbium Lanthanide	66 Dy Dysprosium Lanthanide	67 Ho Holmium Lanthanide	68 Er Erbium Lanthanide	69 Tm Thulium Lanthanide	70 Yb Ytterbium Lanthanide	71 Lu Lutetium Lanthanide
**	89 Ac Actinium Actinide	90 Th Thorium Actinide	91 Pa Protactinium Actinide	92 U Uranium Actinide	93 Np Neptunium Actinide	94 Pu Plutonium Actinide	95 Am Americium Actinide	96 Cm Curium Actinide	97 Bk Berkelium Actinide	98 Cf Californium Actinide	99 Es Einsteinium Actinide	100 Fm Fermium Actinide	101 Md Mendelevium Actinide	102 No Nobelium Actinide	103 Lr Lawrencium Actinide

Of course, in the transition to the upper school (14-18 years) it will be important to teach about the modern atomic view of chemistry and the periodic table as they are a part of contemporary scientific culture and the young people will need to know about this. Up to this age however, it is the ***phenomenology* of the *processes* of the material World** that is most significant in the context of Steiner education.

Summary for Physical Science Curriculum from "Discussions with Teachers"

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
					Physics from out of music:; acoustics. The human larynx from the point of view of physics. Optics Thermodynamics Electricity and Magnetism.	Expand on previous years topics. Continue to study the basics of mechanics. Introduce the chemistry of combustion. Connect physics, chemistry and geography to industrial processes.	Expand on 7^{th} grade and proceed to hydraulics. Continue to connect physics, chemistry and geography to industrial processes. Physics of aerodynamics and climatology. Further chemistry of industrial processes. Organic chemistry

Exercise 1: Energy as a Unity of the Physical Sciences?

In module 2, L4, we introduced Steiner's concept of the inorganic sciences, which include physics, chemistry and technology, amongst other things. There we introduced a part of the following quote which we re-state here:

"*Teacher: I am having trouble with the law of conservation of* energy in thermodynamics.

Dr. Steiner: Why are you having difficulties? You must endeavour to gradually bring these things into what Goethe called "archetypal phenomena." That is, to treat them only as phenomena. You can certainly not treat the law of conservation of energy as was done previously: it is only a hypothesis, not a law. And there is another thing. You can teach about the spectrum. That is a phenomenon. But people treat the law of conservation of energy as a philosophical law. We should treat the mechanical equivalent of heat in a different way. It is a phenomenon. Now, why shouldn't we remain strictly within phenomenology? Today, people create such laws about things that are actually phenomena. It is simply nonsense that people call something like the law of gravity, a law. Such things are phenomena, not laws. You will find that you can keep such so-called laws entirely out of physics by transforming them into phenomena and grouping them as primary and secondary phenomena. If you described the so-called laws of Atwood's gravitational machine when you teach about gravity, they are actually phenomena and not laws". Steiner, R (1919-22): Faculty Meetings with Rudolf Steiner, Anthroposophic Press, p. 28/9.

Consider how you might turn this into a physical sciences main lesson. One option would be to use the idea of the "conservation of energy" as a way to show the integral unity of the physical sciences. As energy is a very topical theme today, it may be a valuable option to introduce this in class 8. As many will know, the future of global civilisation is dependent on energy and the need for a more sustainable form is pressing. An exploration of how energy is generated in its many forms would be one way of showing the holistic unity of the physical sciences as well as providing the young teenagers with an insight into world issues such as energy security and climate change. A possible way to do this would be by introducing the different ways of generating energy from basic sources: coal, gas, oil, wind, biogas, solar, tidal, etc, and how they all involve transformations between the different kinds of physical and chemical energy. For instance there could be a consideration of chemistry of coal, oil and gas can be used in the transformation to heat energy, which in turn can be transformed into mechanical energy, then magnetic and finally electrical energy.

These may then be related to the whole system of physics and chemistry and their connection to industrial, commercial and domestic settings as well as the environmental implications.

Further Exercises

1) Explore what wholeness could mean in the context of the physical sciences.

2) Consider the ear to larynx relationship in acoustics and how they might represent the two polar boundaries of this field.

3) Explore the polarity between light emission and reception: the giving and receiving of light. Consider the application of the inverse square law. Also, investigate the transmission, reflection and absorption of light from a phenomenological perspective. Think about how you might teach this.

4) Using a weighing scale, investigate the different possible phenomena. In this, how would you lead over a teaching session to movement, weight and mass?

5) Design a main lesson which helps the children understand a navigational compass as having its place within the whole magnetic field of the Earth. How would you create an imaginative picture for this using art work?

6) Using phenomena and imaginative presentations, look at how things are set in motion in different ways, kept in motion and stay in motion by themselves. How would you do this with children?

7) Suppose you have a wood burning stove in your classroom and that it is in operation. Devise a lesson about thermodynamics in which you get the children to experience how warmth is distributed differently in the space around the stove and the room; above and below, left and right. Without letting the children actually touch the stove, show how the palm of the hand can be used as a kind of human thermometer.