COMPUTING CURRICULUM SUGGESTIONS FOR A WALDORF SCHOOL

Part 1 of 2
Curriculum Development Approach

by
Bryan Whittle

A Curriculum Study

Research Institute for Waldorf Education

AWSNA

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Preface.

In the late 1970s, when this author was teaching a high school age physics class, a student of about 17 years old announced that his orders of magnitude wrong computed value must be correct "because the calculator said so". It was as if the calculator, and not himself, was the authority that both originated and was accountable for the result. This and related experiences showed me that children (and adults) who are ignorant of how computers work "under the hood" can demonstrate certain susceptibilities that serve to undermine their independent judgment. Students would become "enchanted" in that the computer was being experienced as magical, with strong power from an unknown source. Further observations suggested that students were being pulled in two polar directions:

1. *Being carried away by a feeling of omnipotence.* Students would view themselves as inheriting the power of the computer. This power could seemingly be wielded without the input of work, either intellectual or physical.
2. *Becoming disempowered.* This seemed to have several manifestations:
   - *Losing meaning and giving away authority.* The meaning of the original numbers could be lost at the point of entering them. If the output was 10 or 100, what matter? That is what the authority stated. The possibility of data entry error by the student, such as by "fat fingering" the keys, was neglected. The possibility of a poorly conditioned calculation leading to loss of accuracy was unknown.
   - *Becoming physically will-bound and mentally paralyzed.* Students could become stuck in a doing activity as the provider of input to the machine. This could be accompanied by a paralysis of thinking, and an end to curiosity, in relation to the task.
   - *Becoming dependent and living in fear.* If a calculator was unavailable (forgotten at home, battery ran out, or faulty) some students felt either unwilling ("too much work") or unable ("I'm no good at math") to complete their task by themselves. Students lived in fear of this situation.

More recently, Daniel Golden in his article Unequal Signs in the *Wall Street Journal* of December 15th, 2000 described strikingly similar observations to those reported above but now <u>in elementary schools</u>. Increasingly pervasive and profound enchantment are to be expected owing to the radical shift by people to using computing machines for activities such as calculations and writing that would have been accomplished by hand when I was a young "Baby Boomer". We were the last generation to grow up before the pervasive presence of electronic computers in everyday life. Today, according to Intel[1], "The average American touches 70 microprocessors before lunch." We live in a world of increasingly pervasive "smart objects" such as car systems that mechanize tollbooth payments, personal computers on our desktops, and washing machine cycle controllers in our basements. The "intelligence" is usually implemented via silicon chip resident logic. The denseness of the mechanisms of this technology makes inscrutable both where the power comes from and what an electronic computer can do and can't do. Yet ever more of our thinking work and judgment is delegated to them.

As an alternative to the two polar directions of omnipotence and disempowerment described above, the computing curriculum suggestions herein attempt to lay a concrete path in a third direction toward a healthier relationship between people and computers. This direction resonates with a discernible increasing interest in society concerning what <u>should</u> be done with technology independent of what <u>can</u> be done with technology, including growing interest in what computers are "good for". More attention, enriched by lessons of experience, is being given to unintended consequences of computers concerning the health of people and nature.

A disclaimer is warranted. Although the curriculum suggestions in this paper are offered for use in the classroom, at the time of this writing only some have been carried out as part of a course. These derive from content incorporated from other practicing teachers plus modules used by this author during the 2002-2003 school year at the Waldorf School of Saratoga Springs. This paper was written as a research project as part of a Waldorf high school certification course at New England Waldorf Teacher Training, Inc., Wilton, New Hampshire.

Saratoga Springs, New York, Summer 2003. *Bryan Whittle*

[1] Intel. *One Digital Day.* New York: Times Books, 1998.

0. Acknowledgements.

I am indebted to Valdemar Setzer for his patient mentorship during this project. This has included his reviews of drafts, email exchanges, and making available detailed white papers at http://www.ime.usp.br/~vwsetzer. I recommend these white papers for both their practical content and their perspective concerning teaching computing[2] in high school. Val has taught computing at San Paulo Waldorf School. He can be contacted at the Department of Computer Science, University of São Paulo, Brazil by email to vwsetzer@usp.br. I am also indebted to Michael Shrefl, Professor in the Department of Business Informatics, Data & Knowledge Engineering, Linz, Austria. Email exchanges helped the development of practical content for my first year teaching in Saratoga Springs. Michael has also taught computing at a Waldorf school. I have embraced certain suggestions from these gentlemen so seamlessly into my flow that detailed attribution in this paper is not possible. I claim responsibility for all flaws.

1. Intended readership, scope, and organization of this paper.

Part 1 of this paper is aimed at teachers of students in schools to help foster a dialogue on the development of computing curricula. Part 2 of this paper is offered as a potential aid to lesson planning. As the title of the paper implies, the curriculum nominally aims at a Waldorf school. However, the content is written with a minimum of vocabulary specific to Waldorf schools so as to be accessible to teachers in diverse schools to help foster a wider dialogue on computing curricula.

The scope of this paper is (1) a summary view of the educational needs of students, (2) the exposition of a computing curriculum development method, (3) suggestions for candidate computing curriculum topics per grade, and (4) elaboration of some of these topics into lesson plans and supporting content. The topics emphasize learning about computers before learning through them – practices of good use of computers is a concern of the 12th grade curriculum herein built on a fundament of understanding of computers and their relationship with people. There is intended to be a helpful amount of suggested structure and specific content offered in this paper while not presuming to curtail the imagination of the teacher on which the life of the school depends. The scope of this paper excludes the following:

- Consideration of images of the human being alternative to the anthroposophical viewpoint[3]. These alternatives range across psychological, biological, and mechanistic/chemical[4]. Each choice of image differently informs the purpose of education.
- Details on the developmental needs of children and the Waldorf approach to matching age appropriate curriculum[5]
- Consideration of the expectations of colleges, the expectations of employers, the expectations of politicians, or relationships with businesses that donate computers to schools.
- Consideration of the particular needs of schools that work with a curriculum other than the Waldorf curriculum.
- Consideration of student special developmental needs such as in relation to dyslexia, blindness, muscular dystrophy, and paraplegia.

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[2] "Computing" is used here as a synonym for "computer science". It is preferred here to "computer science" to avoid the suggestion of formalism that does not belong before college.

[3] Steiner, Rudolf. *The Foundations of Human Experience.* Hudson: Anthroposophic Press, 1996.
Steiner, Rudolf. *Theosophy.* Hudson: Anthroposophic Press, 1996.
Steiner, Rudolf. *An Outline of Esoteric Science.* Hudson: Anthroposophic Press, 1997.
Steiner, Rudolf. *How to Know Higher Worlds.* Hudson: Anthroposophic Press, 1994.
Steiner, Rudolf. *Intuitive Thinking as a Spiritual Path: A Philosophy of Freedom*. Hudson: Anthroposophic Press, 1995.

[4] Lievegoed, Bernard. *Phases – The Spiritual Rhythms of Adult Life*. Bristol: Rudolf Steiner Press, 1993.
Dreyfus, Herbert L. *What Computers Still Can't Do: A Critique of Artificial Reason.* MIT Press, 1992.

[5] Steiner, Rudolf. *The Foundations of Human Experience.* Hudson: Anthroposophic Press, 1996.
Steiner, Rudolf. *The Child's Changing Consciousness As the Basis of Pedagogical Practice.* Hudson: Anthroposophic Press, 1996.
Steiner, Rudolf. *Soul Economy and Waldorf Education*. Spring Valley: Anthroposophic Press, 1986.
Steiner, Rudolf. *Waldorf Education for Adolescence*. Forest Row: Steiner Schools Fellowship Publications, 1993.
Steiner, Rudolf. *The Kingdom of Childhood*. Anthroposophic Press, 1995.
Stockmeyer, Karl, *Rudolf Steiner's Curriculum for Waldorf Schools*. Forest Row: Steiner Schools Fellowship Publications, 1991.
Almon, Joan. Education for Creative Thinking: The Waldorf Approach. *ReVision*. Volume 15 No. 2, Fall 1992.

- A review of arguments that advocate[6] or urge caution[7] concerning how much, for what, and when electronic computers are to be used by children in their classroom to learn about the world around them.
- Suggestions for where computing sits in a scheme of priorities for school resources such as the money budget and the daily time budget.
- Suggestions for outfitting a "computing laboratory" (which can be thought of as a part of a larger scope technology laboratory) to provide the needed infrastructure for hands-in work.

The remainder of this paper is organized as follows:

- Part 1, Section 2 briefly characterizes the educational needs of students in terms of both age-specific development needs and the needs of adulthood. As a "response", an age-specific correspondence between student development needs and themes for computing curriculum is developed.
- Part 1, Section 3 lists candidate curriculum topics per grade developed by the method described in Section 2.
- Part 1, Section 4 provides suggestions to meet potential parental interests, including some options for what might be done with computing in the home.
- Part 2 elaborates some of these topics into lesson plans and supporting content.

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[6] For example, see Papert, Seymour. *Mindstorms.* Basic Books, 1993.

[7] For example, see:

Setzer, Valdemar W. *Computers in Education*. Edinburgh: Floris Books, 1989.

Setzer, Valdemar W. A Review of Arguments for the Use of Computers in Elementary Education. Available at http://www.ime.usp.br/~vwsetzer.

Armstrong, Alison and Casement, Charles. *The Child and the Machine*. Beltsville: Robins Lane Press, 2000.

Healey, Jane. *Failure to Connect*. New York: Touchstone, 1998.

David Sloan, Arthur Fink, and David Mitchell. *Computers and Waldorf Education*. Wilton: Association of Waldorf Schools of North America, 1991.

2. Curriculum development method.

2.1 Student needs - the "call".

Curriculum content is the substance on which the student's capacities are schooled and developed. The selection of specific curriculum content is motivated by the underlying purpose of education which, following Rudolf Steiner[8], is taken as both (1) meeting the child's age-specific developmental needs, and (2) preparing the child for the needs of adulthood.

2.1.1 Age-specific developmental needs.

> I remember one morning when I discovered a cocoon in the bark of a tree, just as a butterfly was making a hole in its case and preparing to come out. I waited a while, but it was too long appearing and I was impatient. I bent over it and breathed on it to warm it. I warmed it as quickly as I could and the miracle began to happen before my eyes, faster than life. The case opened, the butterfly started slowly crawling out and I shall never forget my horror when I saw how its wings were folded back and crumpled; the wretched butterfly tried with its whole trembling body to unfold them. Bending over it, I tried to help it with my breath. In vain. It needed to be hatched out patiently and the gradual unfolding of the wings should have been a gradual process in the sun. Now it was too late. My breath had forced the butterfly to appear, all crumpled, before its time. It struggled desperately and, a few seconds later, died in the palm of my hand. That little body is, I do believe the greatest weight I have on my conscience. For I realize today that it is a mortal sin to violate the great laws of nature. We should not hurry, we should not be impatient, but we should confidently obey the eternal rhythm.[9]

What a child needs from the curriculum in support of their development determines the appropriate age for introduction of new content. The focus is not on what the child can do, or can be made to do even if the child were to demonstrate a liking or an aptitude, but rather on what the child needs. Thus the why and the when of the curriculum are bound together. The developing child needs help through both (1) their inner growth, so as to enable their age-specific developing capacities to be schooled and developed, and (2) their studies of outer phenomena, so as to reflect back their inner experience such that the student can experience herself as part of the world unity.[10] These are now considered in turn.

Inner growth.

The inner capacities of thinking, feeling, and willing do not develop at identical rates, but rather the development focus is first on one, then on another. Between 14 and 18 years old, cognitive and intellectual *thinking* awakens strongly. These capacities require schooling and development as they emerge. With these emerging thinking capacities students can come to know computers, as well as other technologies. "Knowing" means that when the student observes a computer the percept unites in her consciousness with the right concept that arises within her[11]; this synthesis of the percept with the concept is the act of knowledge of the computer. This activity requires the student to enter deeply into the algorithmic character of computing, where an algorithm can be viewed as a sequence of unambiguous and mathematically defined steps that lead to a result and halts. This is the same type of reasoning required for mathematical theorem proving. In high school, then, is when the study of computing becomes pedagogically justified.[12]

On the other hand, it is essential that certain content not be delayed too long by analogy with the following observation:

> When a young man takes up surveying as his profession, he begins to study it in his nineteenth or twentieth year at the earliest. There is in our time hardly the opportunity for him to acquire at any younger age the most elementary knowledge of surveying and drawing to scale, or even the use of a measuring rod. But it makes a great deal of difference in after life whether a man has learned something of these things as a boy when about fifteen years old, or approaches them only later, when he is already about nineteen or twenty. At this later age, these subjects will give him the impression of something that is quite outside him. When however a beginning is made in the study of them at about fifteen years of age, they become so

[8] *Waldorf Education for Adolescence*. Forest Row: Steiner Schools Fellowship Publications, 1993.
[9] Kazantzakis Nikos. *Zorba the Greek.* Scribner Paperback Fiction, 1996.
[10] *Waldorf Education for Adolescence*. Forest Row: Steiner Schools Fellowship Publications, 1993.
[11] Steiner, Rudolf. *Intuitive Thinking as a Spiritual Path: A Philosophy of Freedom*. Hudson: Anthroposophic Press, 1995.
[12] For an extensive discussion, see: Valdemar W. Setzer and Lowell Monke. An Alternative View on Why, When, and How Computers Should Be Used in Education. Available at http://www.ime.usp.br/~vwsetzer/comp-in-educ.html.

> entirely one with the human spirit, that they are then the boy's own personal possession, not merely something he has to acquire as part of his professional training.[13]

It can readily be observed that adults trying to relate in a more than superficial way with modern electronic computers often struggle with them as "something that is quite outside" of themselves. Students need to leave high school with penetrating knowledge of a wide range of machines, including but not limited to computers.

With finer granularity, "motifs" of development by year can be identified[14] that urge us to organize our approach to student knowledge of computers in a corresponding progression:

Age	Human development motif
17-18	**Vision: who am I?** Looking for a broad perspective and one's place in it. Looking for a synthesis of all that has been experienced up to this point, both individually and throughout humanity, and to catch glimpses of the future of their own lives and that of civilization.
16-17	**Individuality: why are things this way?** Consciousness is going beyond sense experience. Such a journey requires a new type of thinking – thinking not anchored in what our senses give us – and a confidence that this type of thinking will not lead us astray.
15-16	**Ordering: how do things relate and originate?** Start to relate this to that, weigh, and make judgments. Able to think for themselves with some clarity and confidence.
14-15	**Opposition: what is going on here and now?** A time of being no longer able to obey authority that is accepted as a matter of course and wanting to rely upon oneself. However, a time of tumultuous emotions that cannot be relied on. These emotions arise out of the opposition of the intense materiality of their bodies, the unfolding of puberty, and the immateriality of emerging abstract thinking. Their own thinking can become a steady ballast but it needs to be fashioned.

Study of outer phenomena.

The curriculum must also relate the worldly use of computers to the student. Many technologies could be selected for study. Certain trends in the use of computers justify them for inclusion:

- Increasing pervasiveness. Today, according to Intel[15] "The average American touches 70 microprocessors before lunch." We live in a world of increasingly pervasive "smart objects", e.g., car systems that optimize gas consumption, mechanize toll booth payment, and provide Internet access at the dashboard; compact disk players woven into our knapsacks; personal computers on our desktops; cell 'phones and pagers on our belts; programmable Lego®[16] blocks and microprocessor controlled Barney™ dolls for our children to play with; even internal pacemakers regulating our heart beats.
- Increasingly hidden presence. While pervasive, most chips are embedded within devices that are nominally not "computers", e.g., a washing machine cycle controller. On the Internet we might suppose we are exchanging email with a person but it might be software emulating a person. How can the presence of a computer even be recognized?
- Increasing power. In May 1997 IBM's Deep Blue machine became the first chess-playing computer ever to defeat a reigning world champion when it beat Garry Kasparov in a six-game match - two to Deep Blue, one to Kasparov, and three drawn. Kasparov had been unbeaten for fourteen years in match play. What is the scope of computing power and what are its limitations? What is the relationship between computing and human intelligence? Could machines surpass people as thinkers?
- Increasing inscrutability of where the power comes from. As if by magic, this increasing power comes from a source unknown to many people. Modern computer "intelligence" is usually implemented via silicon chip resident logic. The denseness of the mechanisms of this technology makes inscrutable where the power comes from. While the internal combustion engine cycle is widely known to be occurring under the hood of a car, the "3-stroke engine" of the fetch-decode-execute cycle performed repetitively, precisely, and tirelessly by ever faster electronic circuitry under the cover of a computer is relatively unknown. How can this elusive source of power be understood?
- Increasing delegation of human judgment. Although the source of power is inscrutable, some computer users regard the computer as an authority that originates and is accountable for its results. Some people go as far as to regard computers

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[13] Steiner, Rudolf. *Soul Economy and Waldorf Education*. Spring Valley: Anthroposophic Press, 1986. Lecture 14.
[14] Gerwin, Douglas. High Mowing School - Waldorf High School Curriculum Guide, 1994/1995.
[15] Intel. *One Digital Day.* New York: Times Books, 1998.
[16] All trademarks used in this paper are the property of their respective owners.

to have comparable, even superior, capacities to human thinking. Judgment can be delegated from using the spell checker and grammar checker software to proofread a document to mechanizing missile launch decisions during war. What are good uses for computers and what should not be done with computers?

2.1.2 The needs of adulthood.

The needs of adulthood inform our view of the desired state of preparation when a young person comes of age. In the anthroposophical image of the human being the "I" of a person is the constitutional element that comes of age at 21. In these terms:

> Their "I" works through their thinking, feeling, and willing, and where these aspects of self have been allowed to develop in a harmonious way, the "I" has a strong, clear instrument for its future use. If the instrument is damaged, then young adults will have to work extra hard to bring about a healing so that the individuality can sound forth in a clear and wholesome way. If the mind is fertile and well related to the feelings and the will activity, then there are tremendous possibilities for growth and development throughout a whole life.[17]

These three soul capacities of thinking, feeling, and willing provide for self-education. Self education "distinguishes the adult from the adolescent"[18]. In contemporary society we see an ever increasing need for the adult individual to have the capacities to educate themselves, i.e., take inner responsibility for their own life's direction. These three capacities provide for the diverse needs of the adult workplace such as inner flexibility to adapt to multiple types of occupation over a lifetime; social receptivity to collaborators of diverse cultures, styles, and skills, i.e., "to get on well with his fellows"[19]; and innovative thinking combined the ability to bring that thinking down into a practical reality. One capacity cannot function without the other two, yet each brings its unique challenges to the individual. When we speak of a well-balanced person, we usually mean that all three aspects are active and working harmoniously. If one aspect predominates or one aspect is suppressed we find forms of imbalance, as illustrated by these caricatures:

- The professor living in an ivory tower - a picture of living solely in the activity of thinking, isolated from feelings and will.
- The oversized jock, all brawn and no brain, living in the limbs and in the huge amounts of food they consume - a picture of living wrapped up in the will.
- The bohemian artist, with an existence teeming with human relationships and with little connection to the practical or intellectual - a picture of living wrapped up in the feeling life.
- The "computer nerd" and the television characters Mr. Spock and Commander Data of Star Trek[20] - these embody thinking and will in the absence of feeling, i.e., "Men without Chests".[21]

Although stereotypical and caricaturing, these pictures are helpful in understanding how lop-sided we become if we do not cultivate all three aspects of our soul life. This urges us to provide computing curriculum content that nurtures minds that are fertile and well related to the feelings and the will activity.

In addition to cultivating the three aspects of our soul life as capacities for self-education we need to actually pursue education towards a healthy connection with the reality of technology. We can observe today that adult comprehension for most modern technology tends to be poor leading to a relationship of discomfort with the world. Rudolf Steiner observed as follows:

> Just think how many people today travel by electric train without having the faintest idea of 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 as regards 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 that we know nothing about. This fact, that we understand nothing about something that has been formed by man and is fundamentally the result of human thinking, is greatly significant for the whole mood of soul and spirit of mankind. Human beings literally have to turn a deaf ear in order not to perceive the effects that are resulting from this.[22]

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[17] Almon, Joan. Education for Creative Thinking: The Waldorf Approach. *ReVision*. Volume 15 No. 2, Fall 1992.
[18] Barnes, Henry. *Waldorf Education ... An Introduction*. Fair Oaks: Association of Waldorf Schools of North America.
[19] Steiner, Rudolf. *Waldorf Education for Adolescence*. Forest Row: Steiner Schools Fellowship Publications, 1993. Lecture VI.
[20] http://www.startrek.com/library/bios.asp
[21] Lewis, C.S. *The Abolition of Man.* NewYork: Touchstone. 1996.
[22] Steiner, Rudolf. *Practical Advice to Teachers*. London: Rudolf Steiner Press, 1976. Lecture 12.

With computers as a leading example, modern technologies are becoming more complex and more inscrutable by the user. The world of computing, and technology in general, can seem too overwhelmingly complicated to understand. Not understanding technology can lead to a mental paralysis. People can stop being curious and trying to understand the phenomena they see because “it’s too hard”. Understanding can then be left to specialists. “They” understand. However, the search for understanding is characteristically human. In contrast, accepting the world as it is without trying to associate concepts to percepts, through thinking, is characteristic of animals. If we give up on understanding technology we give up on part of our humanity.

To make matters worse, a mental paralysis with respect to technology can spread to a lack of curiosity and understanding of nature.[23] In part this arises because, in context of ignorance concerning the reality of technology, technology and nature can become indistinguishable. This author first became aware of this possibility when a boy of about 12 years old pointed to a bottle of cow’s milk and declared that the milk had been made in a factory, as indeed some “milk” is. Being brought up in a poor inner city area he had developed no concept of a cow on a farm being milked. However, that which has been brought about by human beings themselves, e.g., computing, is distinct from nature including the nature of human beings. Karl Stockmeyer puts this in an impressive perspective by going so far as to describe technology as a "fifth kingdom":

> Technology, based on physics and chemistry, has created a new world which can be looked upon as part of nature only as far as natural laws operate in it, i.e., no other powers than those active in lifeless matter, But it has also been newly created and added to the old kingdoms of nature, viz. the mineral, plant, animal, and human kingdom. This new kingdom – technology – affects and continually changes the life of man in the strongest possible way.[24]

[23] For example, Ramon E. Lopez and Ted Schultz, Two Revolutions in K-8 Science Education in *Physics Today*, September 2001 references interviews of Harvard University graduates and faculty that revealed commonplace serious misconceptions about the origins of the seasons.

[24] Stockmeyer, Karl, *Rudolf Steiner’s Curriculum for Waldorf Schools*. Forest Row: Steiner Schools Fellowship Publications, 1991. Section 2 Chapter 14.

2.2 Aims of the curriculum - the "response".

In response to the age-specific developmental needs of the child, the Waldorf high school curriculum embodies a year-by-year progression from careful observation to comparison to assisted judgment to independent judgment. Within each stage of this progression, development of the student's thinking can proceed by repeated experience of thinking systematically, moving from specific questions of his or her own to exploration to understanding. For the overall curriculum, examples are given in the Appendix. Suggested themes for high school computing curriculum content can be derived by reflecting on the challenges of understanding modern computing:

- Recognition of even the presence of a computer is a challenge given the embeddedness of most chips.
- Understanding what a computer can do and its limitations is difficult because the embodied lawfulness is embedded in the details of opaque mechanisms.
- Knowledge of where the power, in terms of speed and scope of operation, comes from is hard won given the complexity and inscrutability of the mechanisms.
- Understanding what a computer is "good for" and how it should be used together with human intelligence.

These are key aspects of the "knowledge" of computers to be attained. Without this knowledge we are vulnerable to enchantment (see the anecdote in the first paragraph of the preface). Based on these challenges the following curriculum themes are suggested:

Age	Human development motif "The call"	Grade	Suggested theme "The response"
18-17	**Vision: who am I?** Looking for a broad perspective and one's place in it. Looking for a synthesis of all that has been experienced up to this point, both individually and throughout humanity, and to catch glimpses of the future of their own lives and that of civilization.	12	**Theme: How does computing relate to human intelligence?** Schools and develops the thinking capacity of <u>independent judgment</u>.
17-16	**Individuality: why are things this way?** Consciousness is going beyond sense experience. Such a journey requires a new type of thinking – thinking not anchored in what our senses give us – and a confidence that this type of thinking will not lead us astray.	11	**Theme: Where does the power of a modern digital computer come from?** Schools and develops the thinking capacity of <u>judgment</u>.
16-15	**Ordering: how do things relate and originate?** Start to relate this to that, weigh, and make judgments. Able to think for themselves with some clarity and confidence.	10	**Theme: How have computing machines and their relationship with people evolved?** Schools and develops the thinking capacity of <u>comparison</u>.
15-14	**Opposition: what is going on here and now?** A time of being no longer able to obey authority that is accepted as a matter of course and wanting to rely upon oneself. However, a time of tumultuous emotions that cannot be relied on. These emotions arise out of the opposition of the intense materiality of their bodies, with the unfolding of puberty, and the immateriality of emerging abstract thinking. Their own thinking can become a steady ballast but it needs to be fashioned.	9	**Theme: What is going on with and within mod computers?** Schools and develops the thinking capacity of <u>observation</u>.

The way these themes are approached in the teaching must meet age-specific development needs and needs of adulthood as discussed below.

2.2.1 Meeting age-specific developmental needs.

To meet age-specific developmental needs, the curriculum content must help the student in the following ways:

1. Develop thinking that is clear and logical. This cultivates a general thinking skill and a gratifying sense of order into the soul life. The feeling and willing life of the high school student are to be nurtured still, but the phased schooling and development of thinking is the strongest focus. Following Rudolf Steiner[25], to *know* what they see around them, a person needs to be able to bring the correct concept(s) to the percepts revealed by their senses. It is *thinking* that combines a concept with observation of a particular percept to "round out" the thing to the extent that suffices to answer the questions that arise as consequence of the separation of oneself from percepts in the world. The students are helped to observe phenomena so that they can formulate their own conclusions, learn to explain and defend them, and be able to later revise their knowledge of observations by changing the choice of concept they combine with the percept. There are observations of physical percepts through the physical senses and the corresponding knowing by combining a concept. There are also observations free of physical senses, such as seeing percepts created as will images within the imagination, and the corresponding knowing by combining a concept.
2. Develop thinking that is mobile and permeated with imagination. This cultivates a general skill of thinking in a way that is informed by images that are lawful and meaningful and which hold a greater content than definitions. In general this skill is developed by forming will images and picturing them in lawful movement. Pictures for computing content must be brought by the teacher. Three illustrative examples are summarized here for a microprocessor. The microprocessor executes each instruction within an algorithm called the fetch-decode-execute cycle. A grounded insight into this "3-stroke" cycle takes the student to the core of where the power of a modern computer comes from – from the fetch-decode-execute cycle performed repetitively, precisely, and tirelessly by ever faster electronic circuitry.
    - One imagination can be based on students playing the roles of the machine components[26]; retrospective picturing of these movements, informed by kinesthetic memory, provides imaginative pictures that can inspire within the student the appropriate concepts to unite with the percepts observed by their senses.
    - A second imagination is that of a cashier in a bank. They call the next customer in queue ("fetch"), ask and understand what he wants ("decode"), and do whatever is necessary to fulfill his needs ("execute"), and then repeat again for the next customer.
    - A third imagination[27] is that of "A bureaucracy of file clerks, dashing back and forth to their filing cabinets, taking files out and putting them back, scribbling on bits of paper, passing notes to one another …."
3. Develop thinking that is well related to the feelings and the will activity. This cultivates independent judgment and the ability to bring thinking down into a practical reality. It forms an antidote to imbalances such as the professor living in an ivory tower and the "man without a chest". This development can be approached by deliberately working with all three soul capacities.
4. Develop the ability to think through to solutions to unfamiliar problems. This cultivates persistence, self-confidence, and sense of self. An antidote to bullying, eroticism, and enchantment by authority. This development can be approached by encountering problems that provide opportunity to understand through the student's own thinking, encouraging an attitude that computing is about inquiry and personal involvement, and working with a process of question to exploration to practical knowledge.
5. Ensure the student knows how they know. This cultivates self-confidence and sense of self. It forms an antidote to bullying, eroticism, and enchantment by authority. Development can be approached by ensuring that assumptions are explicit and concepts emerge from practical work such as building working machines.
6. Provide examples of where computing is found in the world. This cultivates an experience of oneself as part of the world unity. It is an antidote to alienation. Development can be approached by rooting the content in realistic every day examples chosen to reflect back the student's age-specific inner experience, including bridges to other curriculum subjects.

Preparing the student for the needs of adulthood.

1. Develop meaningful knowledge about the world through thinking, feeling, and willing.

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[25] Steiner, Rudolf. *Intuitive Thinking as a Spiritual Path: A Philosophy of Freedom*. Hudson: Anthroposophic Press, 1995.
[26] Setzer, Valdemar W. The "Paper Computer" - A Pedagogical Activity for the Introduction of Basic Concepts of Computers. 2000. Available at http://www.ime.usp.br/~vwsetzer.
[27] Feynman, Richard P. *Feynman Lectures of Computation.* Addison-Wesley, 1996. Page 4.

2. Develop appreciation for computing aspects of our culture. This cultivates a well-rounded, competent citizen ready to participate in cultural, economic, and political life.
3. Develop practical skills for use at college and in the workplace.

2.3 Three structural threads of content.

The character of computers is revealed by delving inside. As an analogy, the same could be said of understanding the character of a motor car - lifting up the hood to find the motive mechanisms and figuring out how it all works offers more than learning how to operate the vehicle as a driver. One characterization of “computing” is as the design of algorithms and means for their interpretation.[28] The means for interpretation we can call a “computing machine”.[29] Placing "algorithms" and "computing machine” in context of "history" enables computing to be studied in context of, and as symptomatic of, the evolution of human consciousness. Now we have 3 structural threads of content:

- History.
- Algorithms.
- Computing machines.

These braids can be elaborated and combined together for various purposes:

- Curriculum development.
- Specific lesson plan development.
- Building bridges to other courses in the school.
- Consistency with approaches for other technologies.[30]

[28] An alternative characterization might include a third element of data structures; the point here is not to attempt the best characterization but to show how a characterization can lead on to a multi-threaded content structure.

[29] Synthesizing the evolving dictionary definition of "computer" over time, the means of interpretation of an algorithm could be called a “computer” whether human or machine or a combination. However, the general usage of the word “computer” is insufficiently specific for the scope of interest here and is likely to be misunderstood in places. The phrase “computing machine” is appropriate even to describe the specific activity of a collection of people in a computing team.

[30] This 3-fold thread structure could also be re-used for other technologies. The algorithm thread is specific to computing and requires substitution by the conceptual core of the individual technology; the computing machine thread requires substitution by its implementation counterpart. Thus this paper is envisioned as one of a hypothetical and large set of chapters spanning past, current, and emerging technologies. This structural re-use is suggested to provide an economy in the work of the teacher and the learning process of the students. Karl Stockmeyer’s *Rudolf Steiner’s Curriculum for Waldorf Schools* collects together numerous indications by Rudolf Steiner concerning the teaching of technology that serve as a point of departure for age-appropriate topics.

2.3.1 History thread.

> It is indeed a sinister characteristic of our times that man lives in an environment that is to him an unknown world. Go out into the street and look at the people waiting at the tram stop at the bend of the road, and ask yourself: How many of those people standing there have any idea at all of how the trams are set into motion, how the forces of nature work to bring this about? And do not imagine that this lack of knowledge is without its influence on the whole constitution of man - soul, spirit, and body! It makes a great difference whether or no we go through life having at least an elementary knowledge of the things among which we live. To make use of a means of conveyance or of any other aid or appliance of civilised life without such elementary knowledge, is to go through life blind, - yes, blind in soul and spirit. Just as a blind man goes through the world with no knowledge of the working of light, so do we go blindly through the civilised world **not seeing** the things around us, if we have not taken pains to understand them. It is a defect of soul and spirit; and the troubles that afflict civilised humanity today prove all too clearly that men are blind in this way to what is around them.[31]
>
> In computer science, however, this "infamous characteristic" is present to an extreme degree. Every user of a computer who often has been even superficially introduced to a so-called higher programming language (starting with BASIC or something similar), is misled into believing he understands, although it is only the ability to set unrecognized technical processes in motion that has been given to him; they correspond to mathematical and other logical processes only in a technical way and as an end-product, but not in accordance with reality.
>
> Several fundamental dangers for the activity of human civilization come together here: *On the one hand*, through computer elements or computer-like control mechanisms, assembled on user-friendly handy devices, an intoxication of total power without any need for work (whether spiritual or physical) is produced; *on the other hand*, however, through the cold logic of systematically functioning mechanisms, control is taken out of the hands of human beings, imperceptibly and behind the polished control panels at the "causal thread" of electrical processes.[32]

The historical turning points in the relationship of people with computing provide the content for this thread. In relation to student soul capacity development, this thread helps the student to school and develop the feeling life by *caring* about people in relation to computing. With this thread, all computing curriculum content can be related back to people. To convey this people-relationship motif immediately to the students, a candidate title for the whole computing course might be "People and their computers". Computers are often depicted without a person present; it is suggested that computers are always depicted with a person present such as the designer, the builder, or the operator. The following kind of content pertains:

- **Empathy with computer pioneers and their intentions, ingenuity, and striving.** This is a basis for insight beyond the surface of glass, plastic, copper, and silicon to the underlying human story of the creation of computers. Blaise Pascal was moved by sympathy for his father to invent a mechanical calculating machine to speed and ease his father's computations as a tax assessor. Charles Babbage was fired up to create machines to automate the calculation of tables of mathematical functions with greater accuracy than had been possible previously by hand calculated tables to provide for greater safety for sailors navigating at sea and to relieve the repetitive work of human computers. This is an area concerned not only with the history of computing per se, but also the relations with economics, politics, science, and arts. A symptomatic view of history should be taken.
- **A perspective on the evolving personal relationship of the operator, or "user", with computers.** The historical increase in pervasiveness, power, and inscrutability of computers are examined. Increased delegation of independent judgment of the operator is studied. The student comes into relationship with the designer. Of interest is the point at which an operator begins to find the operation of the instrument inscrutable. Was there a turning point when Blaise Pascal added so many cog wheels to his calculator that the execution of an addition was projected beyond the ability of any person to penetrate? Today it is an even more formidable task to understand the design of a computer chip. This content culminates in the development of independent judgment by the student concerning with what tasks modern computers are well matched, i.e., what are good uses wherein freedom is promoted and enchantment mitigated.

2.3.2 Algorithm thread.

In relation to student soul capacity development, this thread helps the student to school and develop thinking capacities. The student will already know some algorithms, e.g., the Grade 2 algorithm for the sequence of steps for vertical addition with carrying, also called the ripple-carry addition algorithm. For the high schooler, this thread of work brings algorithms out of the "woodwork" and explicitly distinguishes them from general procedures and from flashes of insight.

The key point is the narrowness of the range of problems that can be solved algorithmically. Characterizing an algorithm as a sequence of unambiguous and mathematically defined steps that lead to a result and halts, it can be

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[31] Steiner, Rudolf. *Waldorf Education for Adolescence*. Forest Row: Steiner Schools Fellowship Publications, 1993. Lecture 5.

[32] Schmidt, Thomas. Computer Science and Computers in the Waldorf School: Suggestions for the Technology Curriculum. *Waldorf Science Newsletter*. Volume 3, #5. AWSNA, Autumn 1996.

seen that common procedures such as changing a car tire or social actions such as nurturing a friendship are not algorithmic. Fundamental limitations of computing can be explored in terms of what procedures are and are not expressible in algorithmic form. This progression can build up to a concrete and meaningful exploration of computing in relation to human intelligence.

2.3.3 Computing machine thread.

> One does not need to be endowed with any particular ability to adorn a table with a beautiful bunch of flowers, for Nature is responsible for this. But one must possess a certain amount of practical ability to construct even the simplest machine. This ability is there only one does not notice it because one does not direct one's attention in the right way to oneself. And so ability of this kind (as in technical matters) is, for the unconscious kind of person, highly distasteful if the requisite understanding of objective things is not supplied. Through finding our way into the practical things of life we gradually learn to bear with the intellectual ability which is today poured out over the present age as an abstraction.[33]

The content focus for this thread consists of practical "hands-in" skills concerning construction, repair, upgrade, and recycling, of computers. In relation to student soul capacity development, this thread helps the student to school and develop the will forces through practical skills requiring nimble, persevering fingers and sustained thought. This enables thorough penetration of knowledge of computers and mitigates the fragility of theoretical knowledge and superficial "hands-on" knowledge. Hands-in experience becomes the student's future resource for in-sight about computer design and computer uses.

Recapitulating historical development, four broad design approaches to computing machines can be distinguished and are suggested for use as pedagogical progressions where possible:

1. Human. First, there is the historical progression from people performing computations to then mechanizing parts of those computations. Second, to enter into a dense technology, students can play the role of the mechanical or electronic components.[34] In both cases, computing is firmly related to the student as a human being.
2. Mechanical machines. First, there is the historical progression from human computers to mechanical computers. Second, mechanical approaches can provide an imaginative approach to understanding less penetrable electronic machines, e.g., logic gates implemented with pressure valves[35], and a flip-flop implemented by a vertically clamped saw blade.
3. Electro-mechanical machines, e.g., logic circuits made with relays. This is a next step historically.
4. Electronic machines. This technology is the most difficult to penetrate. For example, opening a transistor package destroys it and the mechanisms are sub-microscopic anyway. The students can deduce the main phenomenological properties of diodes and transistors by testing what happens when voltage is applied. Understanding can be aided with analogous designs of types 1, 2, and 3 above that perform the same function. For example a flip-flop can be constructed first from a vertically clamped saw blade, then from relays, and then from transistors.

This progression can also be used to develop a broad perspective on computing machine design by experiencing how one set of computational rules can be effected by a variety of design choices, and what factors sway those design choices.

Further, collaboration among the students in building working machines can nurture the feeling life. For example, the companion Part 2 document outlines a progression for a 10th grade class to build a binary adder from a set of component circuits such that the end result relies on the sound work and the cooperation of each individual student in the class. Another example is the set of relationships among people in a software team. Such social relationships help towards the sought after balance of soul capacities.

2.3.4 Example approach to braiding a lesson plan.

For lesson content planning, braiding of content from the three threads lends itself to naturally planning around the three soul capacities, both in terms of their distinct qualities and around dynamic relationships as they flow into and contain each other. Further, the three braids lend themselves to a representative treatment of the subject. For example:

<u>Day One</u>:

- From the <u>history</u> content, a story can be told that conveys enthusiasm or love in relation to computing. This could be a biography story told by the teacher about a computer pioneer, or perhaps a personal story by a guest who loves their

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[33] Steiner, Rudolf. *Soul Economy and Waldorf Education*. Spring Valley: Anthroposophic Press, 1986.
[34] For a worked example for an electronic computer, see Setzer, Valdemar W. The "Paper Computer" - A Pedagogical Activity for the Introduction of Basic Concepts of Computers. 2000. Available at http://www.ime.usp.br/~vwsetzer.
[35] Hillis, Daniel W. *The Pattern on the Stone.* Basic Books, 1998.

work in relation to computing. This stirs in the student her *feelings* of enthusiasm or love for people and their interest in computing. These feeling*s* enter and permeate her *will* that is then raised to activity and engaged by the computing machine content. The student builds a computer. Through the need to "figure it out" her will stirs her *thinking*. Thinking in turn enters her *will* to give intentionality to her nimble fingers. Following the hands-in work, just like for a physics experiment, an imaginative recollection of the facts will stir her *feelings* in relation to the hands-in work. These feelings are the fundament needed for the next step.

Day Two:

- ♦ Following sleep, pictures will be present and available to the thinking. Reflections and discussions are possible that, through inspiration, bring to consciousness in the child the laws that stand behind the observed facts. This is the context within which the teacher presents the concepts of algorithm content. Drawing on the precedent of the hands-in work, *will enters her thinking* to form, direct, and connect these thoughts. For 11th and 12th grades, the student can also proceed to form judgments. While the objective content of a judgment lies outside of feeling, for a student to be convinced of the correctness of a judgment then *feeling in the thinking* must develop.
- ♦ By deferring until Day Two the conjoining of concept with the percepts from Day One, a practice for "living thinking" is cultivated. This progression aims to enable the student to form her own relationship to the facts, and then the concepts that arise can become her own. (In contrast to a method that would first present concept and then proceed to illustration.) Further, this affords the student freedom to make judgments and conceptual interpretations that may grow in the child and transform over time yet remain tethered to a living and clear experience of factual content. This latter quality is necessary for personal growth.

2.3.5 Bridging to other subjects.

For integration with other subjects, the organization of content into threads lends itself to designing specific bridges. For example:

- ♦ For history, biographies of computer pioneers could be integrated into history lessons or drama plays. Drama would contribute further to the feeling content of the computing course. Art classes can provide related examples, e.g., for "abstraction".
- ♦ For algorithms, selected topics such as binary arithmetic could be integrated into mathematics lessons.
- ♦ For computing machines, some electrical and electronic circuit design could be integrated into physics lessons and making components, e.g., Napier's rods, could be integrated into woodwork and metalwork lessons.

3. Candidate curriculum topics.

3.1 Published computing curriculum progressions for Waldorf schools.

Existing literature on computing curriculum content progression published by Waldorf educators is here briefly reviewed as sources of inspiration. The references provide much more than the listings abstracted here.

Valdemar W. Setzer and Lowell Monke. [36]
Note that this content is integrated into a broader technology curriculum.

10th Grade

- logic and phenomenological study of computer hardware
  - DC electric circuits with batteries, resistors, LEDs, magnets, relays
  - logic gates with relays
  - simple applications, e.g., traffic lights
  - gradual emergence of formal terminology and symbols

11th Grade

- logic and phenomenological study of computer hardware
  - binary and decimal numerical bases
  - half adder
  - full adder
  - flip-flop with relay
  - diodes, transistors - redo adders and storing devices with them
  - computer components
- machine language
  - basic concepts of stored programs
  - internal functioning

12th Grade

- principles of programming
  - understanding how programming languages work (without actual programming)
  - word processors, spreadsheets, graphics, database systems, and their internal structures
  - computer networks
  - browser, chat systems, usenets, e-mail, remote file transfer, remote access to databases
  - general notion of algorithms
- use of computers in the learning process
- effects of computers on society and the individual

[36] Valdemar W. Setzer and Lowell Monke. An Alternative View on Why, When, and How Computers Should Be Used in Education. Available at http://www.ime.usp.br/~vwsetzer/comp-in-educ.html.

Thomas Schmidt.[37]
Note that this content is integrated into a broader technology curriculum.

9th Grade

- history of discoverers and inventions
- number systems including binary
- relay based binary calculator

10th Grade

- Jacquard's loom

11th Grade

- Electronics
  - semiconductors
  - abstraction
  - diode
  - transistor
  - redo 9th grade relay circuits with transistors
  - build flip-flop
    - mechanical flip-flop with vertically clamped saw blade

12th Grade

- von Neumann machine
- computer compared with a person
- higher languages, e.g., relevant to school administration
- relation to social and individual problems

[37] Schmidt, Thomas. Computer Science and Computers in the Waldorf School: Suggestions for the Technology Curriculum. *Waldorf Science Newsletter*. Volume 3, #5. AWSNA, Autumn 1996.

David S. Mitchell & Andrew Linell.[38]

1. Introduction
    - look inside a PC
    - word processing
    - social questions
    - history
        - tools
        - people
        - processes
        - field trips
    - applications

2. Literacy
    - machine language
    - flow charts
    - higher languages

3. How does it work
    - architecture
        - Boolean algebra
        - binary review
        - De Morgan's Law
    - practical
        - breadboards, chips, wiring
        - build one bit adder
        - build R-S flip-flop using only NAND gate
        - build 4-bit J-K shift register

[38] David S. Mitchell & Andrew Linell. Thoughts on a Prototype Computer Program for Waldorf High Schools. *Waldorf Science Newsletter*. Volume 4, #7. AWSNA, Autumn 1997.

Charles Tolman.[39]

1. Historical summary
2. Double light switch circuit construction
3. Binary numbers and arithmetic
   - half adder
   - addition algorithm
   - idea of 2 bit full adder
4. Computer architecture
   - 2 bit full adder
   - Colossus
   - Alan Turing
   - ENIAC
   - Stored program control
   - PC disassembly and reassembly
5. Algorithms
   - sort exercise based on work by V.W. Setzer and F.H. Carvalheiro.[40]
   - Paper Computer play based on work by Valdemar Setzer.[41]
   - TV/video
6. Video editing

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[39] Tolman, Charles. Computer Technology Teaching. Available at http://www.cix.co.uk/~charlest/index.html.
[40] Setzer, V.W. and Carvalheiro, F.H. "Algorithms and Their Analysis." 2000. Available at http://www.ime.usp.br/~vwsetzer.
Setzer, V.W. "New Chapter 5 on Algorithms." 2002. Available at http://www.ime.usp.br/~vwsetzer.
[41] Setzer, Valdemar W. The "Paper Computer" - A Pedagogical Activity for the Introduction of Basic Concepts of Computers. 2000. Available at http://www.ime.usp.br/~vwsetzer.

A Waldorf high school computing teacher - partial curriculum.[42]

9th Grade - practical comfort

- historical overview
- look inside a PC
- typing
- produce a document

10th Grade - build a calculator

- PC disassembly
- transistor
- logic circuits
- Boolean algebra
- solving logic problems
- half adder
- full adder
- 2-bit binary calculator

11th Grade - programming

- machine level
- assembly level
- hardware-software combination
- microprocessor

12th Grade: ?

[42] Personal conversation.

John Morris at Lexington - partial curriculum.[43]

8 or 9th Grade - "demystification"

- history
  - von Liebniz and binary arithmetic
  - Napier and logarithms
  - Pascal and his calculator
  - Babbage and his analytical engine
  - Jacquard and his loom
  - Lovelace and her programming
  - Hollerith and his counting machines
  - Boole and logic
  - portraits of pioneers
  - acting, e.g., vignette of life in France during the Thirty Years war … Cardinal Richelieu presses commoners for taxes to wage war …. revisions to tax rules …. Blaise Pascal's father works harder as a tax collector …. Blaise responds with the calculator.
- technologies
- magnetics for memory and disk drives
- relay based calculators
- visit to Boston's computer museum
- use of computers, e.g., weather prediction, air traffic control, automated directory assistance, reading for the blind.

[43] Reported by Steve Talbott in *Netfuture* Issue #54, July 30, 1997.

3.2 12th grade candidate topics.

With the theme from Section 2 "How does computing relate to human intelligence?" in mind, candidate topics are identified below:

1. **Computing and human intelligence.** A condensed version is elaborated in Part 2.
    - Examples of computing "intelligence".
    - Limitations of computing.
        - Algorithms - review from Grade 11.
        - Limitations of abstraction.
        - Electronic calculator - review of limitations of capacity, precision, and accuracy, from Grade 10.
        - Relationship between accuracy and meaning.
        - Undecidability.
            - Emil Post's correspondence problem.
            - Universal Turing Machine and the halting problem.
    - Turing test for "intelligence".
        - Definition of the test, the Loebner Prize.
        - Eliza program, Eliza's successors, e.g., ALICE, Ella.
        - Anonymity on the Internet – machine or person on the other end?
    - Searle's Chinese Room Experiment.

2. **Good use of computers.** A version is elaborated in Part 2.
    - For what tasks are electronic computers a match?
      - an approach to using computer products with judgment.
    - Moral action with computers – discussion topics.
        - Postulate guidelines for the operator concerning when to use a computer.

3. **Future potentialities of computers.**
    - Types of distributed computing, e.g., human computing team, SETI project, peer to peer computing, cluster computing.
    - Nanocomputers, including an imagination of pervasive nanocomputing.
    - Beyond silicon, e.g., quantum computers, DNA computers.
    - Evolutionary algorithms.
    - Fuzzy logic.

3.3 11th grade candidate topics.

With the theme from Section 2 “Where does the power of a modern digital computer come from?” in mind, candidate topics are identified below:

1. **Algorithms.** A version is elaborated in Part 2.
    - Method of differences algorithm via the human computing team.
    - Everyday procedures contrasted with algorithms
    - Review algorithms the students already know, e.g., decimal vertical addition
    - History of algorithms from Ancient Egypt through Knuth.
    - Relative efficiency of alternative sorting algorithms; practical limitation of machine processing capacity due to an intractable amount of computation.

2. **Stored program control.** A version is elaborated in Part 2.
    - The fetch-decode-execute cycle.
    - Instruction set.
    - Machine language.

3. **Bit level logic "below" the instruction set level.**
    - Binary digits
        - Henry Morse and the first telegraph system, to introduce a binary system.
        - Review of Jacquard's loom and Hollerith's census counter use of bits, from 10th grade.
    - Implementing logic gates.
        - George Boole.
        - Human analogue -> mechanical analogue -> DC electric circuits using batteries, resistors, manual switches, and relays -> transistor circuits.
        - Applications, e.g., binary adder, tic-tac-toe machine, traffic light controller.
    - Implementing “memory”.
        - Flip-flop.
        - Shift register.
    - Microprocessor.[44]

4. **Application level logic "above" the instruction set level.**
    - Programming.
        - A procedural programming language.
        - Contrasts of an object-oriented language.
        - Components of a development environment.
        - How a specific application program works, e.g., text editing.
        - HTML or XML.
        - User-centered design.
    - Operating system, including kernel distinction from bundled applications.

5. **Computer networking.**
    - Set up a computer network with PCs, a printer, and Internet access.
    - IP networking and how the Internet works.
    - The Internet as intersecting intentional communities.

[44] Could Pysanky eggs be painted to experience the photoresist process that is used to layer circuits into silicon?

3.4 10th grade candidate topics.

With the theme from Section 2 "How have computing machines and their relationship with people evolved?" in mind, candidate topics are identified below:

1. **Finger math.**
2. **The "user" arises.** A version for the abacus is elaborated in Part 2.
    - Counting with stones.
    - Implement an abacus.
3. **Mechanical adder.**
    - Story of Blaise Pascal and his calculator of 1642.
    - Implement the essential mechanism.
    - How many cogs wheels can you follow imaginatively until the mechanism becomes too complex?
4. **Multiplication machines.** A version for Napier's rods is elaborated in Part 2.
    - Story of John Napier.
    - Implement Napier's rods.
    - Implement the essential mechanism of a mechanical multiplier.
    - Implement a slide rule.
5. **Human computing teams.** A version is elaborated in Part 2.
    - Story of Baron Prony and division of computing labor, inspired by Adam Smith's Wealth of Nations.
    - Implement a computing team (the algorithm is to be explained in 11th grade).
6. **Difference engine.**
    - Story of Charles Babbage and Ada Lovelace.
7. **Mechanization of instructions: towards the stored program control machine.**
    - Theory of Babbage's analytical Engine designed to enable a choice of programmed numerical calculations, 1832.
    - Story of Jacquard mechanizing the loom weave pattern, 1862.
    - Story of Herman Hollerith's Census Coding Machine mechanizing manipulation of non-numerical census data, 1890.
    - Story of John von Neumann and the von Neumann architecture, 1940s.
    - Human emulation of a von Neumann machine.
    - Disassemble and assemble a PC again and identify the subsystems corresponding to the von Neumann architecture.
8. **Electronic calculator.** A condensed version is elaborated in Part 2.
    - Limitations of capacity leading to overflow and underflow.
    - Limitations of accuracy due to limitations of precision due to limited capacity of number representation.
9. **Comparison of the above computing machines.** A version is elaborated in Part 2.
    - Can the user understand how the computing machine works?
    - What is the relative power, in terms of speed and scope of operation, of each machine?
    - What is the functionality of each machine in terms of the components of the von Neumann architecture?
    - What are the limitations of each machine?
    - How much judgment does the user delegate to each machine?

3.5 9th grade candidate topics.

With the theme from Section 2 “What is going on with and within modern computers?” in mind, candidate topics are identified below. The focus progresses from the PC on the desktop to use of computers in the environment, inspired by the 4th grade local geography block progression to world geography in later grades.

1. Identification of components within a modern computer.

- Identification of components and the internal organization of a PC.
- PC disassembly.
- Demanufacture components, e.g., take apart an old disk drive.
- Reassembly and configuration of the PC.
- Loading, installing, and configuring a commercial application

2. Lifecycle care of a modern computer.

- How applications drive requirements for upgraded capabilities.
- How required capabilities plus von Neumann architecture drive component design.
- Upgrade the PC due to a new requirement.
- Tasks for routine maintenance.
- Troubleshooting and repair using a systems approach.
- Recycling obsolete components - where do all the old computers go?

3. Modern computer use survey.

- Observe and describe how are computers used in the school, e.g., school office, library.
- Observe and describe how are computers used on the road, e.g., traffic counters, toll debit machines, car engine control.
- Observe and describe how are computers used in the home, e.g., compact disk player, personal computer, washing machine, telephone/answering machine, robot toy.
- Observe and describe how computers are used in the neighborhood, e.g., price from bar code on goods, inventory control in stores, health monitoring in hospitals, Internet Service Providers.
- Field trips, if there is an opportunity to explore the use in some depth.

3.6 Middle school candidate topics.

Between the approximate ages of 7 and 14 years old, the child's *feeling* life is the most strongly developing capacity. All that is taught through imagination and the arts penetrates deeply. Human relationships are of great importance at this age. Creativity, imagination, and an orderliness and healthy respect for boundaries are qualities that when fostered during this period will emerge later in the students' thinking as well. Following the emergence of an historical consciousness around the age of 11 years old, the curriculum responds with a progression in the content of the history block from 5th grade study of ancient civilizations through 9th grade modern history. It is natural to include computing in cultural context from 5th or 6th grade onwards. The emphasis is on the relationship with people. Construction of the essential aspects of devices of the time provide for deeper penetration into the perspective of the time. The content is to be presented consistent with the consciousness of the time, e.g., view an abacus from the perspective of a person of ancient Egypt and not with any modern slant such as a comparison with a von Neumann machine. The materials used for the computers, the degree of refinement of the design, and the relationships with people can all help provide a feel for identity of the people of that time. Further, when the student starts to build computing machines they are recapitulating a progression they have already experienced as a human computer in their own math in grades 5 through 1 because the historical progression of computing machines recapitulates the computational progression from counting to addition, e.g., using abaci, to multiplication tables, e.g., using Napier's rods. Just as for the history curriculum, there is later a recapitulation of the 5th-9th grade computing themes from 10th grade through 12th grade but with a strong thinking component.

The history and computing machine threads could be integrated into history lessons or math lessons; this extra cultural aspect as well as the hands-in work could enrich either course. Nothing is needed for algorithms that goes beyond the traditional arithmetic the students meet with in the mathematics classes. Candidate projects for middle school are given in the table below:

Age	Human development motif "The call"	Grade	Candidate projects "The response"
13-14	**What is going on here in the world today?**	8	**Construction of non-electronic computing Machines ~1700 to present,** e.g., Baron de Prony's human computing teams.
12-13	**I want to explore and experiment; I'm skeptical of your authority.** Shares with the Renaissance personality the questioning of authority, the fascination with personal exploration and experimentation.	7	**Constructing computing machines Renaissance (~1400-1600) through ~1700,** e.g., Napier's rods.
11-12	**I want to know and control this world.** Deeper descent into matter shares with the Roman personality a desire for earthly law and the honor and purity of earlier years gives way to a fascination with grossness, with laziness, with self-indulgence.	6	**Computing machines - ancient Egypt, Greece, Rome (~400-1400) to Medieval,** e.g., abacii.

What might lead to adoption of such a middle school curriculum? One possibility is to respond to student interest in computers.

3.7 Prior to middle school.

Prior to middle school no new curriculum content is needed. Existing content is directly relevant for later work when computing becomes an explicit subject. For example, when the 6th to 9th graders build computing machines they are recapitulating a computational progression they have already experienced as a human computer in their own math in grades 5 through 1, and when the 11th grader studies algorithms they can refer to the grade 2 algorithm for vertical addition with carrying. Existing elements of curriculum should be "left alone" and any temptation to mould these elements to even better fit a "computing curriculum" be resisted. There is an analogy there to beginning the study of physics in 6th grade – by then the student has much sense-based phenomenological experience to draw upon from previous years although that experience was not gained for the purpose of doing physics.

In the first seven years of life, the child is primarily living in the will, learning nearly everything through physical activity. During these years, learning takes place mostly in an unconscious manner through the child's imitation of the activities of adults and older children. Yearning and imaginative imitation are appropriate to meet the needs of the child at this age.

4. For the parent: a way of thinking about the curriculum.

Through newspapers, magazines, television, radio, friends, relatives and neighbors parents are subjected to what the "experts" say about the need for children to use computers. For example see Valdemar Setzer's review of arguments for the use of computers in education.[45]. Most of the volume of opinion is in favor of use of electronic computers earlier than suggested in this curriculum. The curriculum herein must address these "digital divide" concerns such as:

- Will the children fall behind in their understanding of the world?
- Will the children be handicapped at college and in the workplace?
- What is to be done at home if computers are not used at school?

4.1 A "picture of health".

The computing curriculum herein aims to help the student reach a healthy relationship with computers. In general the curriculum aims to help the student develop (1) a harmonious, well-balanced, personality with a mind that is fertile and well related to the feelings and the will activity and (2) an experience of themselves as part of the world unity. With respect to computing, the specific "picture of health" is that a 12th grade graduate:

- Feels related to the intention of the people who originate the technology.
- Recognizes a computer when they experience one.
- Knows where the power of a computer comes from.
- Knows what a computer can do and what are its limitations.
- Can construct, take care of, and diagnose the repair needs of a computer.
- Can form an independent judgment concerning whether and why a computer is good for the task at hand.

This picture is offered as a worthy outcome, worth striving for, and worth waiting for. This picture could be a "rallying place" among stakeholders with highly diverse, sometimes polarized and emotionally charged, viewpoints concerning the role of computers in the education of children. Perhaps it is easier to agree on the desired state than the path to the desired state? The curriculum suggestions in this paper show a path to this result while embracing electronic computers at a "late and convenient hour" in the child's development and showing how existing Waldorf curriculum in the lower grades can be genuinely related to computing without necessitating "keyboarding" or "pointing and clicking". Thereby it is hoped that concerns about achieving timely competency on the one hand and concerns about preventing premature exposure on the other hand can both be met.

Throughout this paper the computing curriculum content is presented "backwards", from Grade 12 to 9 rather than N/K to 12, so we can always "work backwards" from this picture of the desired state of the 12th Grader.

4.2 Curriculum elements before 6th grade are relevant just as they are.

Some parents may be concerned that their children "don't start computing until sixth grade". However, when the 6th grader starts to build computing machines (according to the suggestions herein) they are recapitulating a progression they have already experienced as a human computer in math in their earlier years because the historical progression of mechanical calculators recapitulates the computational progression from counting to addition to multiplication tables.
One cautionary note. It is intended here that the existing elements of curriculum be "left alone" and any temptation to mould these elements to even better fit a "computing curriculum" be resisted.

4.3 What might be done in the home?

As outlined in Section 2 above, the developing child needs two-fold help through both (1) their inner growth so as to enable their age-specific developing capacities to be schooled and developed, and (2) their studies of outer phenomena so as to reflect back their inner experience such that the student can experience themselves as part of the world unity. Both needs call for the student to have a home life harmonious with their school life.

In the first seven years of life, learning takes place mostly in an unconscious manner through the child's imitation of the activities of adults and older children. For example, this author heard a parent describe how their child made "computers" from pen, paper, and play stands and played with them in imitation of her parents. Yearning, imagination, and imitation are appropriate to meet the needs of the child at this age. It is a common observation that children love to play with empty

[45] Setzer, Valdemar W. A Review of Arguments for the Use of Computers in Elementary Education. Available at http://www.ime.usp.br/~vwsetzer.

cardboard boxes once the contents are emptied (sometimes of supposed-to-be-fascinating toys). This suggests that parents who need to use a computer at home during the day could have a cardboard box or two lying around and available for the child to make a “computer” so they can imitate the adults.

For ages eight through eighteen years of age, one approach to sustaining harmony with school life is to act consistency with the curriculum approach in Section 2 above. To the extent the student shows interest in computing, they can engage in related activities, e.g., reading a biography of a computer pioneer, figuring out an efficient algorithm for someone guessing what page they are on with a "minimum" number of guesses[46], or making a functional and beautiful abacus. However, there are strong cultural and social pressures that bear on parents and students to use electronic computers at an early age. In practice there is no need to begin early. Modern computers and applications are readily learnt as the necessity arises, and are becoming ever easier to operate. One possible approach to bearing with the pressures is to cultivate in the family a "looking forward" to a "rite of passage" of delving deeply into this dense modern technology analogous to how families look forward to the farm trip in 4th grade or the introduction of physics in 6th grade.

The practical question arises at to what should be the position of a school that recommends against the use of electronic computers by children if the students already have and use computers in the home. While consistency between school and home might be out of reach, the situation can be made coherent for the student by the school continuing to not use computers for education until high school computing studies begin and to acknowledge that there is the potential for variance from the home environment. Such variances already exist, e.g., a “no pictures on clothes” rule at school at variance with pictured T-shirts at home, and occasional wine drinking at home that would be out of place at school.

4.4 Readiness for college and the workplace.

This computing curriculum is intended to be a foundation for all students regardless of the direction of their future studies and occupations. At the same time, the content suggested here provides context and perspective in which to set further education in the discipline of computer science; teaching with living thinking intends to support personal growth by allowing conceptual interpretations to transform over time yet remain tethered to a living and clear experience of factual content.

The content suggested herein provides context and perspective in which to develop specific skills relevant to college and professional life such as operation of a particular word processing program. The 12th grade curriculum herein intends to provide the student with experience of operating commercial products, e.g., a PC, operating software applications for communication across the Internet, and to create electronic documents. However, this is done in the context of helping the student to form independent judgments about appropriate use of computers. This way, when they are at college or the workplace, they will have resources to draw upon concerning combining the "how to" with the "when to". Further, it is a matter of common experience that, given some hands-on familiarity with a PC, learning a new application takes but a few days. There seems to be no compelling merit in an extensive course of product training at high school.

[46] My son likes to play this game of "guess what page I'm reading".

Appendix: Human development "call" and example Waldorf curriculum "responses".[47]

Age	Human development motif "The call"	Grade	Curriculum motif and themes "The response"
18-17	**Vision: who am I?** Looking for a broad perspective and one's place in it. Looking for a synthesis of all that has been experienced up to this point, both individually and throughout humanity, and to catch glimpses of the future of their own lives and that of civilization.	12	**Motif: independent judgment.** Schools and develops the thinking capacity of independent judgment. **Example themes:** ♦ **Subjects that synthesize many themes, related to the centrality of the human being.** e.g., world history, architecture, Faust.
17-16	**Individuality: why are things this way?** Consciousness is going beyond sense experience. Such a journey requires a new type of thinking – thinking not anchored in what our senses give us – and a confidence that this type of thinking will not lead us astray.	11	**Motif: Judgment.** Schools and develops the thinking capacity of judgment. **Example themes:** ♦ **Working imaginatively with the invisible.** Pointing to something we can know though physical-sense free thinking. Nature examples: Physics – electricity that can be seen only by its effects; chemistry – atomic theory; math – beyond deductive logic to the infinities of projective geometry. ♦ **Pointing to ideals.** Culture examples: History – Medieval and Renaissance individual quests and journeys.
16-15	**Ordering: how do things relate and originate?** Start to relate this to that, weigh, and make judgments. Able to think for themselves with some clarity and confidence.	10	**Motif: Comparison.** Schools and develops the thinking capacity of comparison. **Example themes:** ♦ **Balance.** Nature examples: physics - mechanics; chemistry - acids and bases; earth science - self-regulated weather processes; embryology - the play of masculine and feminine influences; math – surveying. Culture example: ancient history – how did the here and now all come about? ♦ **Clear logical thinking.** Example: math - trigonometry, progressions, logarithms, number bases.

[47] The human development content of this table for Grades 12 through 9 is based on Douglas Gerwin's High Mowing School - Waldorf High School Curriculum Guide, 1994/1995.

Age	Human development motif "The call"	Grade	Curriculum motif and themes "The response"
15-14	**Opposition: what is going on here and now?** A time of being no longer able to obey authority that is accepted as a matter of course and wanting to rely upon oneself. However, a time of tumultuous emotions that cannot be relied on. These emotions arise out of the opposition of the intense materiality of their bodies, with the unfolding of puberty, and the immateriality of emerging abstract thinking. Their own thinking can become a steady ballast but it needs to be fashioned.	9	**Motif: Observation.** Schools and develops the thinking capacity of observation. **Example themes:** ♦ **Here and now.** Nature example: local geology; Culture example: history - 19th and 20th century. ♦ **Opposition.** Nature examples: physics - heat and cold; chemistry - expansion and contraction of gases; geology - collision of plate tectonics. Culture examples: history - conflicts and revolutions in France, Russia, and North America. ♦ **Exact observation and reflection.** This develops an objective imagination of outer phenomena and is the fundament of thinking. This capacity can be later applied in Grade 11 to inner development and to invisible outer phenomena. "A healthy path of development can only be traveled in the balance of the path outwards and the path inwards, in that order. For on the outward path thought is strengthened in such a way that it can stand up to overwhelming experiences on the inward path."[48] Nature examples: science - exact description without overlay of theory; humanities - précis of events or of a character. ♦ **Order within chaos.** Example: Math – permutations, combinations, probability (rules of order underlying apparent chaos), loci (including navigation at sea).

48 Lievegoed, Bernard. *Phases*. Rudolf Steiner Press, 1993.