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 in elementary schools. 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 should be done with technology independent of what can 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.

[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

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[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

[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]

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[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 independent judgment.
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 judgment.
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 comparison.
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 observation.

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 11^{th} 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 6^{th} to 9^{th} 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

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[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.

COMPUTING CURRICULUM SUGGESTIONS FOR A WALDORF SCHOOL

Part 2 of 2
Lesson Plan Outlines and Content Overviews

by
Bryan Whittle

A Curriculum Study

Research Institute for Waldorf Education

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0. Focus of this Part 2.

When children relate what they learn to their own experience, they are interested and alive, and what they learn becomes their own.[1]

The lesson plan outlines and supporting content overviews below elaborate some parts of the curriculum in Part 1. The curriculum topics are assigned to 12th, 11th, 10th, and 9th as would be expected from Part 1. The manner in which the student's soul capacities are engaged can be broadly inferred from the thread of curriculum content; in addition, some detailed examples are given of how soul capacities are engaged in a balanced and dynamic way including the role of sleep.

The author's experience with this content is based on classes from the 2002-2003 school year at the Waldorf School of Saratoga Springs at which the computing course was confined to the 12th and 10th grades. The curriculum topics in Part 1 were configured as summarized in the table below – the numbers indicate the order of units in the two courses:

	Part 1 12th grade candidate topics	Part 1 11th grade candidate topics	Part 1 10th grade candidate topics	Part 1 9th grade candidate topics
Saratoga 12th grade course	3. Computing and human intelligence. 4. Good use of computers.	1. Algorithms. 2. Programming.	none	none
Saratoga 10th grade course	none	4. Morse code. 5. Logic gates.	1. Abacus. 2. Napier's rods. 3. Human computing team. 6. Electronic calculators.	none

Some anecdotal experience from teaching is reported below by past tense references to "Saratoga students". This was the author's first attempt to elaborate the curriculum in Part 1. Only some content has been elaborated to date. Of the three threads of content outlined in Part 1, the history thread is the least developed.

[1] Henry Barnes, *Waldorf Education … An Introduction*. Fair Oaks: Association of Waldorf Schools of North America.

1. 12th grade: good uses of computers.

A "day" here is a 45 minute class – the 12th grade Saratoga students had 4 such distinct classes per week.

Outline of lesson plans.

- Days One and Two
  - Synthesis of threads: For what tasks are computers a match - an approach to using computer products with judgment.
- Days Three and Four
  - Synthesis of threads: Moral action.
- Days Five and Six
  - Synthesis of threads: Guidelines concerning when to use a computer.

Overview of content for Days One and Two.

- For what tasks are computers a match? Good use of computers concerns the practice the student brings to their personal use of computers. The context for this work is a project that calls for use of commercial application software running on a PC and involves use of the Internet. This provides a "realistic" setting for establishing a practice of good use. Acting morally on computers requires an independent judgment as to whether the computer is a good match for the task in mind including whether the computer is being used for the good in relation to people. In relation to student soul capacity development, this question aims to help the student to school and develop and synthesize willing, feeling, and thinking required to form independent judgment:
  - Clarity of *thinking* informed by the student's understanding of what the computer can do based on work in grades 9, 10, 11, and 12.
  - The *feelings* that enter and inform the thinking. 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 must develop. Further, empathy for people enters into the judgment of whether the use is good in relation to people.
  - The *will* to act with commitment in relation to the outcome of the judgment.

  In relation to the outer world the student can develop experience and skills to judge whether and why a computer use is "good" for the task in mind, i.e., they can act morally upon computers. There is no intent to "moralize" here. By going through a process of making a considered judgment concerning the appropriateness of use for a computer the possible inclination to become will-bound is mitigated and the will can undergo a maturation process:

  > Willing is the same soul-activity as thinking, but willing is still a child. When it grows a little older, it becomes feeling, and when it is quite old it is thinking. The matter is made difficult by the fact that the different ages live together in our soul in these three activities.[2]

  This maturation can take place from one day to the next where sleep plays a critical role.[3] Periods of not doing are required to enable that which is fired up in the will to mature in the warmth of our heart as feeling and then further mature in our cool head as thoughts.
- The students proceed with an introduction to products such as Microsoft Explorer, Microsoft Outlook Express, and Microsoft Office applications. Skills of how to use and judgment concerning when to use are held together. The students work through diverse concrete tasks, e.g.,
  - Write a business letter combining text, a table, and graph of financial results. Has enough thinking been done before the letter is started? Should there be a handwritten draft first?
  - Obtain some credible facts for the letter from the Internet. Where is the Internet helpful and not helpful? How can sources be validated?
  - Perform an elaborate calculation for the business letter. Where is a spreadsheet useful, e.g., repetitive "what-if" computations and those dependent on parameters? Where can it be a distraction, e.g., when developing a personal feel for orders of magnitude?
  - Communicate the same information to many people. Where is email helpful, e.g., to overcome geographic or temporal separations?

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[2] Steiner, Rudolf. *The Balance in the World and Man, Lucifer and Ahriman*. North Vancouver: Steiner Book Centre, Inc., 1977. Page 33.

[3] This maturation can take also take place over long periods of time, such as the three initial seven year cycles of development which is reflected by the broad sweep of curriculum content progression.

- Identify events that compromise the integrity of the task, e.g., can the spellchecker replace proofreading, and is attention being drawn away from the task to how the products operate?

Overview of content for Days Three and Four.

- Where is the use moral, i.e., what is a computer "good" for? Are there certain tasks that a computer ought not to be made to do, independent of whether computers can be made to do them? Some focused questions that can be discussed open-endedly in a whole-class setting are as follows:
  - Unknown presence of a computer. A checkers playing program was tested[4] by playing against people at the Microsoft Network Gaming Zone Web site (www.zone.com). Based on the number of games played and the performance the machine was awarded a "Class A" rating – one level below the designation of "expert" following the United States Chess Federation rating system. Opponents were not told they were playing against a program, nor did any of them appear to guess that their rival was a program. Some people praised the ingenuity of their competitor. Should they have been told?
  - Unknown presence of a computer. Given that a company selling goods uses software to analyze incoming customer e-mail and compose response e-mails, should we be told that the response we receive is mechanized?
  - Replacing people. Given web-based software that can be used to emulate a psychotherapist to enable widely available and affordable "therapy" on the Internet, should this be made freely available?
  - Replacing people. Given a sufficiently sophisticated and affordable chess program that could beat most schoolchildren, should it be used to represent the school in chess matches rather than "less able" students?
  - Hacking. "White hat" hackers identify and publicly publish security flaws in products, such as Microsoft Windows. On the one hand this enables the manufacturers and the users to become aware of the problems and repair them; on the other hand, "black hat" hackers can use this information to attack vulnerable users before a repair has been put in place. Are white hat hackers doing the right thing?
  - Legal responsibility. Napster combined a centralized database service and distributed PC software to enable computers to exchange music; this was used by people to exchange music without paying copyright royalties to the music owners and makers. Does Napster have any responsibility for the copyright violation by its customers?
  - Human multitasking. Is it generally accepted that a person can walk and chew gum at the same time and do both "well". Mothers are known to be able to rock a baby and sew a torn vest at the same time and do both "well". However, is it possible to drive a car, hold a conversation on a mobile telephone, and check incoming e-mail at the dashboard and do all three "well"? What limits on multitasking should we consider when we work with computing machines? What capacities does a computer have that enable it to multitask, or appear to multitask, "well"? Do people have these capacities?
  - Unintended consequences. Computers can cause organizational forms to ossify. Weizenbaum[5] illustrates: "The belief in the indispensability of the computer is not entirely mistaken. The computer has become an indispensable component of any structure once it is so thoroughly integrated with the structure, so enmeshed with its vital substructures, that it can no longer be factored out without fatally impairing the whole structure. That is virtually a tautology. …. The computer was not a prerequisite to the survival of modern society in the post war period and beyond; its enthusiastic, uncritical embrace by the most "progressive" elements of American government, business, and industry quickly made it a resource essential to society's survival *in the form* that the computer itself had been instrumental in shaping." Discuss how to mitigate such a problem.
  - People's special needs. Consider that a brain-computer interface can be used to help people with severe paralysis to make physical actions.[6] The person intentionally modulates certain components of the electrical signals emitted by their brain, which is then recorded by an electrode-covered cap. A computerized signal-processing algorithm converts the signal into a command for a prosthesis. An example prosthesis consists of electrodes implanted under the skin in such a way as to choreograph movement in the muscles of the arm and hand so as to grasp a pen. Is this is a "good" use for computers?
  - Whither Artificial Intelligence. Consider Ray Kurzweil's view[7] that in the future: "We will also be able to scan a particular person -- let's say myself -- and record the exact state and position of every

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[4] Bawa, Joanna. *Computers and Your Health*. Berkeley: Celestial Arts, 1996.
[5] Weizenbaum, Joseph. *Computer Power and Human Reason*. Penguin Books, 1984.
[6] Chase, Victor D. "Mind Over Muscles." *MIT Technology Review.* March/April 2000.
[7] Kurzweil, Ray. *The Age of Spiritual Machines.* Penguin Books, 1999.

neurotransmitter, synapse, neural connection, and other relevant details, and then reinstantiate that information into a neural computer of sufficient capacity. The person that then emerges in the machine will think that he is (and had been) me. He will say "I was born in Queens, New York, went to college at MIT, stayed in Boston, walked into a scanner there, and woke up in the machine here. Hey, this technology really works." Consider this in relation to limitations of computing such as algorithms and abstraction.

- Information overload. How should that be managed? Considerations include:
  - Distinction between “data”, “information” as theoretical knowledge, and “knowledge” as practical personal knowledge.
  - More thoughtful sending to others.
  - Designing systems with the other person in mind.
  - The phenomenon of “peek-a-boo” information[8] that is hot today and gone tomorrow.
- Physical injury. A repetitive stress syndrome called carpel tunnel syndrome is increasingly common in corporations. It arises from typing and using a mouse at personal computers. How should this be mitigated?
- Limitations of information on the Internet. The web is a repository of finished thoughts of others. These valuable crystals correspond to the end product of thinking. Not all finished thoughts are available on the Web. Care is needed to evaluate the significance of information, e.g., credibility of authorship. What is the role of the Internet in supplying us with information?
- Chat rooms. Unlike face to face communication or telephone conversations you cannot be sure of the identity of who is on the other end of the line. What approach is appropriate?
- The rules of the day-to-day functioning of some commercial businesses are being given to computers. Enterprise Resource Planning software, originally designed for manufacturing plants, has been generalized to automate back office functions and increasingly front office and head office functions. The main leverage looked for by the company is reduced staffing costs. During remediation of Year 2000 computer issues[9], the risk management plans of some corporations revealed that the body of people who, by definition, are the corporation would not know how to run the business if the computers failed at the millennium. They had delegated away the knowledge of how to run the business. Is that OK?
- Computers sometimes mechanize missile launch decisions during war. What safeguards are necessary? The leverage looked for by military organizations is increased decision speed. In 1961 J.W. Forrester commented on developments on combat automation since his 1947 memorandum to the U.S. Navy "On the Use of Electronic Digital Computers as Automatic Combat Information Centers”:

  > … one could probably not have found [in 1947] five military officers who would have acknowledged the possibility of a machine's being able to analyze the available information sources, the proper assignment of weapons, the generation of command instructions, and the coordination of adjacent areas of military operations …. During the following decade the speed of military operations increased until it became clear that, regardless of the assumed advantages of human judgment decisions, the internal communication speed of the human organization simply was not able to cope with the pace of modern air warfare. This inability to act provided the incentive.[10]

Overview of content for Days Four and Five.

- This curriculum content aims to help the student to school and develop their independent judgment in relation to using modern electronic computers by developing a positive practice for deciding whether computers are right for the task at hand. Accordingly, the guidelines are developed through brainstorming and reflection.
- Some candidate questions to evoke guidelines concerning when (as distinct from how) to use a computer are as follows:
  - Can the task be understood independently of the computer? If not, does the task needs penetrating more deeply or redefining? This step has two purposes:

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[8] Postman, Neil. *Technopoly – The Surrender of Culture to Technology.* New York: Vintage Books, 1993.

[9] The Year 2000 (Y2K) issue is the result of systems with computers using two digits rather than four to represent the applicable year. As they make turn of the millennium based computations, they may interpret "00" as the year 1900 rather than the year 2000, or may not properly treat the year 2000 as a leap-year. Depending on how the date is made use of this could result in system failures or miscalculations.

[10] Forrester, J.W. in M. Greenberger, editor, *Managerial Decision Making in Management and the Computer of the Future.* MIT Press, 1962. Pages 52-53.

    - First, it reinforces the intentionality of the operator around the task. This concerns the student keeping to the task and not being refocused on "getting the program to work" rather than completing the task.
    - Second, the unavailability of the computer then becomes a more manageable problem and less a source of fear. The student should have a contingency plan as to how to finish the task if the computer breaks.
- Where would the computer be helpful with the thinking process? What care must be taken when delegating judgment?
    - Is delegation of a repetitive task OK? Perhaps to allow the operator to focus their capacities on more creative aspects of the task?
    - Is performing a computational task that would take "too long" for people to do OK? What is "too long"?
- Is there a plan to retain ownership of accuracy and meaning? For example, doing a "back of the envelope" calculation or performing the final and authoritative proofreading.
- Are there physical challenges to be met? A repetitive stress syndrome called carpel tunnel syndrome is increasingly common in corporations. It arises from typing and using a mouse at personal computers. What are technology based and other approaches to mitigating this problem?

2. 12^{th} grade: computing and human intelligence.

A "day" here is a 45 minute class – the 12^{th} grade Saratoga students had 4 such distinct classes per week.

Outline of lesson plans.

- Day One
  - History thread: examples of computing intelligence.
- Day Two
  - Algorithm thread: review of algorithms from 11^{th} grade.
- Day Three
  - Algorithm thread: abstraction and its affect on meaning.
- Day Four
  - Algorithm thread: abstraction and its affect on meaning.
- Day Five
  - Algorithm and computing machine thread: review of electronic calculator limitations from 10^{th} grade; accuracy and its relationship to meaning.
- Day Six
  - Algorithm thread: undecidability.
- Day Seven
  - Algorithm thread: undecidability.
- Day Eight
  - Algorithm thread: Turing test for "intelligence".
  - Algorithm thread: Eliza and successors.
- Day Nine
  - Synthesis of threads: Computing and human intelligence.

Overview of content for Day One.

- Nowadays, some people go as far as to regard powerful computers to have comparable, even superior, capacities to human thinking. The students bring some examples of the reasons why.
- Some leading edge examples are:
  - In May 1997 the 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. IBM's computer "Deep Blue" was a RISC System/6000 model weighing 1.4 tons and looks like a black refrigerator. In 1996, Kasparov had beaten Deep Blue in three out of six games with two draws. In 1989, Kasparov played Deep Blue's predecessor, Deep Thought, and won all the games. What had changed in the machine that lost in 1996: more powerful hardware, a more extensive chess database, and a program to change the parameters in between each game. Concerning power, new hardware had the ability to analyze 200 million moves a second, compared to Kasparov's estimated 3 moves a second. Thus in the three minutes usually allotted during tournaments for a chess player to make a move the machine could make 40 billion calculations of possible moves.
  - Experimental mathematics is using computer-aided proofs to augment the capabilities of human mathematicians. As examples:
    - Refutation of Euler's conjecture that at least N Nth powers would be required to sum another Nth power (three cubes, four fourth powers, etc.). Frye was able to find a counterexample by using a combination of conventional analysis and computer search[11] :
      (95,800)**4 + (217, 519)**4 + (414,560)**4 = (422,481)**4 =
      31,858,749,840,007,945,920,321
      Finding such a counterexample exceeds the capability of a human mathematician either doing mental arithmetic or using a paper and pencil.
    - The problem of whether four colors are sufficient to color any map. Haken and Appel attained the proof in 1976 using 1,200 hours of time on a then-powerful electronic computer[12]. The computer

[11] Stewart, Ian. *From Here to Infinity*. Oxford University Press, 1996. Page 36.
[12] Stewart, Ian. *From Here to Infinity*. Oxford University Press, 1996. Page 105.

searched through a large but finite number of possible maps that were specified in advance by Haken and Appel. Thereby the computer searched exhaustively for a counterexample. Human mathematicians have no way to check the computer's work since it would take many lifetimes.

Overview of content for Day Two.

- Algorithms from grade 11 are reviewed. See Section 4 below.

Overview of content for Day Three.

- While abstraction is used in other contexts, it is suggested the topic of abstraction be treated in relation to meaning. "What is the meaning of my computational results?" is a crucial question for a 12th grader to be working with in order to be able to self-direction to their life in a contemporary culture of pervasive computing.
- Partly due to its familiarity, and partly to warm the coldness of the topic of abstraction in the context of computing, the explicit process of abstraction is introduced through art. The students are asked to compare and contrast a series of four sculptures by Henri Matisse:

Back I, 1909, *Back II*, 1913, *Back III*, 1916-17, *Back IV*, 1930, are four bronze sculptures about 6 feet high and 4 feet wide by Henri Matisse. In the succession of works, the axis of the spine becomes the increasing focus of the composition. In 1908, Matisse wrote:

> In a picture, every part will be visible and will play the role conferred upon it, be it principal or secondary. All that is not useful in the picture is detrimental. A work of art must be harmonious in its entirety; for superfluous details would, in the mind of the beholder, encroach upon the essential details.[13]

The class arrives at a general view that an abstraction is a design technique that selects the essential aspects of a situation and conceals non-essentials. There is a conversation about the rise of abstraction in 20th century art and computing, both exploring forms that by their abstract nature carry some abstract intellectual content.

- The students are asked to design the essential items of data for a sales tracking system to determine salesperson wages based on commission. The system could be a paper one initially and then be mechanized as the business grows larger. The students are asked to make a list of attributes of a person and then a second list of which aspects are essential to be represented so their wages can be calculated monthly. The results are pooled and a common list starts to form:
  - Essentials for the abstraction "salesperson" are few, e.g.,
    - Name
    - Unique identifier, e.g., social security number, or unique company identifier
    - Dollar value of sales
    - Commission rate
  - Inessentials are many, e.g.,
    - Personal appearance
    - Medical history
    - Family configuration
    - Food preferences

  Then wages for (Name, Unique identifier) can be computed as Dollar value of sales x Commission rate. The unique identifier is required to disambiguate two identical names.

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[13] Barr, Alfred H. *Matisse: His Art and His Public.* Arno Pr., 1967.

- The students are asked to consider the design of a medical system to provide records for a person requesting medical treatment. The system could be a paper one initially and then be mechanized as the practice grows larger. The students are asked what aspects of a person are essential to be represented. The list starts to form:
  - Essentials for the abstraction “patient” are few, and different even for the same person from “salesperson”:
    - Name
    - Unique identifier, e.g., social security number, or patient identifier
    - Medical history
    - Family medical history
  - Inessentials are many:
    - Dollar value of sales
    - Commission rate for sales …

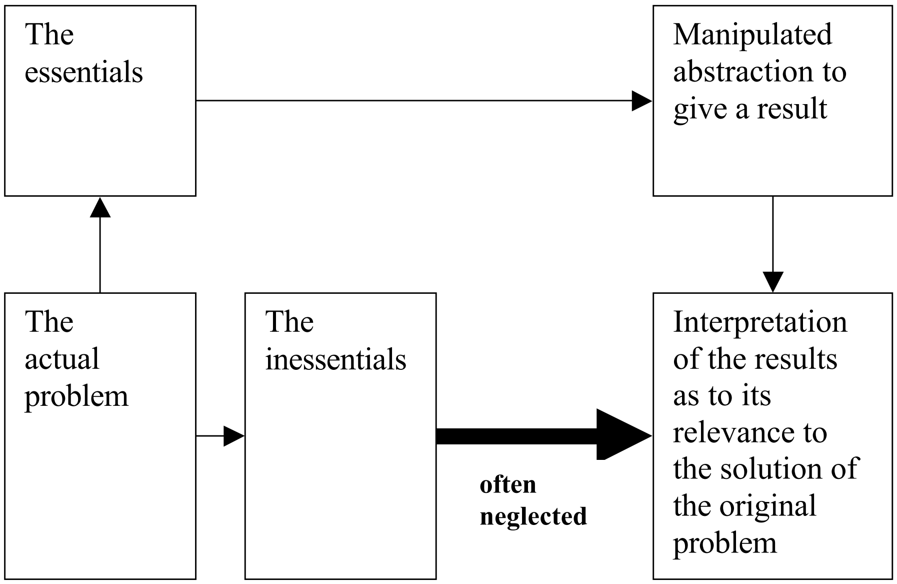
  Then unique identifier can be used to access the record of data for Name.
- The intent for working with the soul capacities of a student on this day is as follows. A natural enthusiasm arises when writing a list of attributes of a person. These feeling*s* enter and permeate her will that is then raised to activity and engaged by the manual activity of writing down the attributes. Through the need to figure out the abstraction the student’s will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers, e.g., is the space of attributes to be drawn flat or patterned? Then an imaginative recollection of the facts stirs her feelings in relation to the hands-in work. These feelings are the fundament needed for the next step.

Overview of content for Day Four.

- The intent for this day is that, following sleep, pictures are present and available to the thinking. Reflections and discussions are possible that, through inspiration, bring to consciousness in the child the general rules that stand behind the observed examples from yesterday. This is the context within which the teacher presents the concepts of abstraction. Will, which can draw on the precedent of the manual work, enters her thinking to form, direct, and connect these thoughts. By deferring until this day the conjoining of concepts with the percepts from the previous day, a practice for “living thinking” is cultivated.
- The students reflect on whether the “salesperson” and “patient” abstractions have all the required essentials. The students identify desirable properties of an abstraction, e.g.,
  - Contains only what is essential.
  - Suggestively named.
- A conversation is held concerning the large number of abstractions in which one person can “participate”. The students consider the importance of limiting the use of each abstraction to its original purpose. The diminished view of the person in the salesperson model should not be used for other purposes not intended by the model, e.g., to mechanize annual retention decisions based on value to the company – that could miss key contributions such as “mentorship to other employees” and outstanding long term financial contribution. Weizenbaum states the following:

  > … models embody only the *essential* features of whatever it is they intended to represent. If a model of an automobile is intended for wind tunnel tests, then the outside shape of the model car is important, but no seats nor any other interior furnishings of the real automobile need be present in the model. What aspects of reality are and are not embodied in a model is entirely a function of the model builder's purpose. But no matter what the purpose, a model, and here I am concerned especially with computer models of aspects of reality, must necessarily *leave out almost everything* that is actually present in the real thing. Hence what can be learned from manipulating the model is strictly limited *in every case*. Whoever knows and appreciates this fact, and keeps it in mind while teaching the use of computers, has a chance to immunize his or her students against believing or making excessive claims for much of their computer work. [14]
- Thus an abstraction can represent a problem by a model that can be manipulated algorithmically. Certain aspects of the problem complexity and detail are "abstracted away". The art of abstraction concerns the judgment, which improves with practice, of which details have little to no effect on the solution so we can have confidence that the model lets us deal with the essence of the problem. The actual problem is transformed into, in a sense "replaced" by, the model. Therefore the computing machine does not solve the actual problem – rather it solves a model of the problem. Then we must concern ourselves with how "good" is the model and how to interpret the "results" of the computation in relation to the original problem. Again this requires judgment. As we interpret the results do the inessentials still seem inessential? A picture that can be used to convey an often neglected step in the process of abstraction is shown below:

[14] Weizenbaum, Joseph. *Computer Power and Human Reason*. Penguin Books, 1984. Page xvii.



Overview of content for Day Five.

- Capacity and its limiting affects on precision and accuracy are reviewed by repeating the electronic calculator limitations exercise from 10th grade. See Section 5 below. A discussion is engendered concerning how accuracy relates to meaning, and how ownership over accuracy is retained by further scrutiny on our part, e.g., to determine if the result is reasonable and consistent with other observations. For example, our hypothetical power company from grade 10 work could have a quite wrong meaning associated with its precisely expressed but inaccurate numbers for power loss – they could spend millions of dollars trying to fix a problem that does not exist. Precise inaccuracy, with attendant loss of meaning, also appears in qualitative work, e.g., a software spell checker will approve the "correct" spelling of the wrong word such "on" instead of the intended "one". That example further illustrates how accuracy relates to meaning. As a quantitative example, if a certain experiment yielded the magnitude of the acceleration due to gravity as 980 meters per second per second (rather than the accurate 9.8), would it really feel right in relation to our everyday experience of falling objects? As a further exploration of the distinction between precision and accuracy, one can observe that in order to be more accurate in relation to a certain meaning, you might even have to be less precise, e.g., a researcher for Encyclopedia Britannica reviewed the question of whether the world's "largest" bear should be based on height or weight. "I leave it up to you," he wrote to the Britannica editors, "to decide whether we stay with the Kodiak … go with the polar bear, or fudge."[15] Thus we may be unable to decide unambiguously which is the world's "largest" bear, but that might be less important than having a full and rich appreciation of "large" bears.

Overview of content for Day Six.

- Undecidability, in the form of Emil Post's correspondence problem, is introduced as a "domino" play. The students work in pairs to create a warm social event and to help each other solve the problems. Each pair makes 8 domino-shaped slips of paper from one writing sheet. Domino types are made with strings of letters on their upper and lower halves. The task is to place dominos from the collection, repetitions allowed, such that the upper string and lower string created by concatenating the strings on the selected dominos are identical.
- A worked example teaches the approach: given {A/AA, ABA/B}, the students can use two instances of the first domino and one of the second domino to find the answer (A/AA, ABA/B, A/AA). Saratoga students asked for many clarifications of the rules, e.g., must each domino type be used (yes), can the dominos have their upper string and lower

[15] McCarthy, Michael J. "Britannica Plies the Info Highway." *Wall Street Journal.* April 22, 1999.

string swapped (no), can the dominos be used with just their upper string or just their lower string (no)? The Saratoga students explored the rules looking for flexibility and found little.

- Then other problems are given to solve, e.g.,
  1) {AB/A, A/AA, AA/B}
  2) {B/CA, A/AB, CA/A, ABC/C}
  3) {X/Y, A/B}
  4) {ACA/AC, AB/A, AB/B}

  The answer for 1) is (AB/A, AA/B, A/AA, A/AA), and for 2) is (A/AB, B/CA, CA/A, A/AB, ABC/C). The question of uniqueness of the solution is acknowledged in passing or investigated. For 3) no solution is possible since there are no common letters at the lower and upper halves. For 4) no solution is possible since all strings at the upper halves are longer than the strings at the lower halves such that the upper concatenation will always be longer than the lower concatenation and thus they can never coincide. Students are asked to share their experience as to how they came to know that the problem could not be solved. 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 must develop. Most of the Saratoga students had an experience of the knowledge coming to them as an emerging insight after considerable pondering; a few had continued to search for a solution.
- The intent for working with the soul capacities of a student on this day is as follows. First, a natural enthusiasm arises when working in a team. These feeling*s* enter and permeate her will that is then raised to activity and engaged by the manual activity of making the dominos, and then trying domino configurations to find a solution. Through the need to figure out the correspondence the student's will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers, e.g., is the correspondence beginning to appear? Following the hands-in work, an imaginative recollection of the facts stirs her feelings in relation to the hands-in work. These feelings are the fundament needed for the next step.

Overview of content for Day Seven.

- The intent for this day is that, following sleep, pictures are present and available to the thinking. Reflections and discussions are possible that, through inspiration, bring to consciousness in the child the general rules that stand behind the observed examples from yesterday. This is the context within which the teacher presents the concept of undecidability. Will that can draw on the precedent of the hands-in work enters her thinking to form, direct, and connect these thoughts. By deferring until this day the conjoining of concept with the percepts from the previous day, a practice for “living thinking” is cultivated. The undecidability concept is introduced today as a plausibility argument – it could be replaced later in life by a formal mathematical proof while leaving intact the student’s underpinning experimental experience with dominoes.
- The students are asked to determine an algorithm that takes any array of domino types as input and produces as output a solution to the problem or asserts that no solution is possible. A lot of exploration of approaches is appropriate here. Ultimately the teacher might need to create a systematic path such as the following. First a solution for 1 domino – either the top string matches the bottom or it does not. Then a solution for 2 dominos - using the experience from the previous day the students could test whether all letters on upper halves are different from all letters at lower halves and whether each domino has a longer string at the upper half than at the lower half. However, this will not cover all cases. A proliferation of cases starts up as differing numbers of symbols are considered. The possibility arises that testing possible solutions could go on forever for lack of a comprehensive set of conditions for no solution. This insight is confirmed by the teacher to be true for the general procedure for any array of domino types – the sought for algorithm does not exist. Thus we cannot find an algorithm to solve this problem. Therefore we could not mechanize the solution with software. At the same time, people seem to be able to solve new particular instances of this undecidable problem. This opens up a deep truth in computing and a deep truth concerning the relationship between people and computing. They deserve some quiet space in which to be respectfully held.
- Students are given further examples of how the undecidability problem manifests in today's computers:
  1) It is not possible to construct an algorithm that can determine, for all procedures, whether another procedure will halt.
  2) It is not possible to construct an algorithm that proves, for all algorithms, that an algorithm is correct.
  3) It is not possible to construct an algorithm that, for all virus algorithms, will detect that virus. Thus a "virus shield" can never detect all possible viruses. Only once a new virus has been found a new checking condition can be added to the virus shield. The new "virus" has to be found and identified by a human!

Overview of content for Day Eight.

- In 1950 Alan Turing proposed a test: There are two keyboards in front of you, one connected to a computer, the other leads to a person. You type in questions on any topic you like; both the computer and the human type back responses that you read on the respective computer screens. If you cannot reliably determine which was the person and which the machine, then we say the machine has passed the Turing test. It is noted that the Loebner Prize Contest at http://ww.surrey.ac.uk/dwrc/loebner runs annually and awaits a winner that passes such an unrestricted Turing Test.
- However, we can restrict the test to give the computer a fighting chance. One such restricted test has been done where the problem area is restricted to chess games and the second restriction that you only see the recorded moves of a previous game. Now you must state if either opponent, or possibly both or possibly neither, was a computer. In an informal experiment, Garry Kasparov could occasionally, but not reliably, guess from recorded games whether opponents were human or machine. Note that many strategies would be open to you in a test without this second restriction, e.g., you might deliberately lose the game in a way that might reveal the identity of your opponent.
- The Turing test is set up in the classroom. The Eliza program is downloaded[16] or run off a web site.[17] Saratoga students did not run the Turing test for logistical reasons, rather they ran Eliza directly. Saratoga students considered certain behavior as telltale that Eliza is not human:
  - Some repetitiveness.
  - Some nonsense statements.
  - Sometimes combined responses to multiple statements in an unthinking awkward way.
  - Showed a lack of initiative.
  - Sometimes had blanks in responses as if the form of the response was predetermined but a keyword was missing.
  - Despite the significant issues above, Eliza corrected trivial typographical errors by the students.

  These characteristics were considered telltale even if Eliza were to be considered a Rogerian psychotherapist[18] who can legitimately communicate as if they had a limited knowledge of reality.
- "Improvements" on Eliza, such as ALICE[19] and Ella[20], have fewer telltale behaviors. Saratoga students felt that some repetitiveness and nonsense statement remained.
- The student's experience of Eliza, ALICE, and Ella is considered in terms of algorithms. What kind of algorithm might be at work, e.g., looking for keywords? How might the telltale behaviors be cleverly mitigated?

Overview of content for Day Nine.

- Reflecting on yesterday, people seem to be able to solve new particular instances of undecidable problems but algorithms, by their very character, cannot. This positions the class to enter into a general but concrete discussion of the relationship between computing and human intelligence. People, through free personal insight can think through problems for which no algorithm exists whereas computing machines are constrained to interpret algorithms. Further, people can then decide to act on their thinking in this way or that way whereas computing machines are constrained to "act" in a predetermined configuration. To broaden the discussion consider a social problem such as "how can I make my two friends speak to each other again". Each case is another case. It is fundamentally not a mathematical problem, e.g., there is no meaning for our friends in estimating a probability based on outcomes of "similar" cases even if abstractions were used to characterize a similar case.
- To give further concrete perspective to the capacities of computing machines, and the ingenuity of their creators, a way of thinking about a legitimate "superiority" of electronic computers is discussed. When children learn about animals in 4th Grade, the teacher introduces them by relating their capabilities and form to those of people. Specific animals can do specific things "better" than people but they are rather specialized in these talents. Current students are surrounded by "smart objects". Robots or programs can exhibit behavior that is in some sense superior to people, e.g., quickly, accurately, and tirelessly performing a repetitive task that can be expressed algorithmically. This is a narrow superiority that can be healthily granted to the machine. An aspect that makes the narrowness hard to see sometimes is that computers appear to be non-specialized because of their programmability – their functionality depends on the program they interpret. Nevertheless, the algorithmic thinking style is so limited that overall the capacity is narrow.

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[16] For example, http://www.spaceports.com/~sjlaven/eliza.htm has an MS-DOS program for download.
[17] For example, http://www-ai.ijs.si/eliza/eliza.html has a web-based version of Eliza.
[18] Weizenbaum, Joseph. "ELIZA – A Computer Program For the Study of Natural Language Communication Between Man and Machine". *Communications of the ACM*. January 1966.
[19] http://www.alicebot.org
[20] http://www.ellaz.com

- ♦ The historical mission of computing is explored. This can provide guiding context for a more detailed symptomatic treatment of the historical turning points in the relationship of people with computing. The development of technology affords us an opportunity for freedom or for bondage.[21] Consider digging a hole in the ground in three different ways:

Method used	Physical willpower engaged
Bare hands	Most
Spade	Some, e.g., drive spade into ground with foot
Back hoe	Least, i.e., move joystick to and fro

The increasing physical cutting and leverage afforded by the machines increasingly separates physical willpower from the task at hand. Then willpower is freed up for other things, e.g., to be applied to creative thinking to better plan the project. However, there is a temptation to become dependent on the machines and if we forget to apply some of our increased thinking opportunity to learning how to fix back hoes then if the back hoe breaks we have to abandon the job (at least until the "expert" arrives). In recent times, the analogous situation for thinking has arisen. This is the contribution of the computer. Consider three ways to perform addition of a list of numbers:

Method used	Thinking engaged
Mentally	Most
Abacus	Some, e.g., individual calculations are done mentally
Modern personal computer	Least, e.g., operate the control panel on a spreadsheet

The increasing intellectual cutting and leverage afforded by the machines increasingly separates thinking from the task in mind. Then thinking is freed up for other things, e.g., to be applied to creative thinking to better plan the project. We must remain mindful of potential downfalls such as the following:

  - ➢ Being carried away by a feeling of omnipotence. Viewing oneself as inheriting the power of the computer, to be wielded without the input of intellectual or physical work. That is an illusion of self-development.
  - ➢ Becoming disempowered with respect to the task in mind. This could happen in multiple ways, e.g., losing the meaning of the task, giving away authority over the task, becoming physically will-bound and mentally paralyzed as the provider of input to the machine, becoming dependent and living in fear of a computer break down.
  - ➢ To offload lesser thinking tasks but then not do the inner work of more advanced thinking to transcend to higher consciousness. This could lead to one's own thinking degrading to an algorithmic computing intelligence.

- ♦ This is all suitable for an essay question. Saratoga students variously tackled "Are computers becoming smarter than people or are people becoming dumber than computers" or "What does a healthy relationship with a computer look like".

[21] For an extensive discussion see Setzer, Valdemar W. "The Mission of Technology". 1996. Available at http://www.ime.usp.br/~vwsetzer.

3. 11^{th} grade: stored program control.

- Several previous activities prepare the way for an explicit treatment of stored program control in 11^{th} grade. In the 10^{th} grade curriculum, analogies are made to memory, processing, and data input/output in a modern electronic computer for each of the machines made. In the 9^{th} grade, the von Neumann architecture is identified in terms of the components of a PC.
- The next step is a detailed human emulation of the components of the von Neumann machine. Valdemar Setzer's Paper Computer exercise[22] has thoroughly worked this through. This gives a concrete first experience of an instruction set and the fetch-decode-execute cycle. The content is tested and ready for classroom use by others.
- The next step introduces machine language. Valdemar Setzer's machine language exercise[23], including an MS-DOS machine emulator available for download, has thoroughly worked this through. Using the emulator is straightforward and the programming gives a concrete and understandable experience of how the instruction set, machine language, and the fetch-decode-execute cycle all work. The content is tested and ready for classroom use by others.

[22] 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.
[23] Setzer, Valdemar W. "The HIPO Computer - A Tool for Teaching Basic Computer Principles through Machine Language". 2000. Available at http://www.ime.usp.br/~vwsetzer.

4. 11th grade: algorithms.

A "day" here happens to be a 45 minute class – the 12th grade Saratoga students, for whom these 11th grade topics were included, had 4 such distinct classes per week.

Outline of lesson plans.

- ♦ Day One
  - ➢ History thread: Baron de Prony's human computing teams.
- ♦ Day Two
  - ➢ Computing machine thread: experiencing being a human computing team.
- ♦ Day Three
  - ➢ Algorithm thread: how does the method of differences algorithm work?
  - ➢ History thread: what happened to human computing teams?
- ♦ Day Four
  - ➢ History thread: Muhammad ibn-Musa Al-Khowarizmi.
  - ➢ Algorithm thread: the character of an algorithm.
- ♦ Day Five.
  - ➢ Algorithm thread: well-designed algorithms.
- ♦ Day Six
  - ➢ Algorithm thread: development of sorting algorithms.
- ♦ Day Seven
  - ➢ Algorithm thread: testing of sorting algorithms.
- ♦ Day Eight
  - ➢ Algorithm thread: analysis of sorting algorithms.

Overview of content for Day One.

- ♦ The teacher gives the story of Baron Gaspard de Prony's invention of computing teams in the 1790s[24]. He was commissioned by the French government to prepare extensive mathematical tables, e.g., logarithms and trigonometric functions of angles. Accurate tables were essential for correct navigation; sailor's lives were at stake, and for other purposes. Prony was inspired by the concept of division of labor put forth by Adam Smith in Wealth of Nations[25], recently published in 1776. The first chapter, on division of labor, describes how manufacturing processes can be broken down into small steps, each performed repetitively by specialized workers. Most of de Prony's workforce came from the ranks of unemployed hairdressers, the fashion for powdered wigs having died out with the French Revolution. Prony organized his force of mathematicians into three echelons: at the top were six outstanding men that did the analytical work to determine what was to be computed by which formula; the second echelon was comprised of eight skilled calculators who knew algebra and could use the formulas to make detailed calculations of values at regular intervals and carry the work to where it became the repetitive addition or subtraction of numbers in difference tables. Then the third echelon, comprised of seventy men, did only addition and subtraction rapidly and fairly accurately. To increase accuracy, each number was computed at least twice in different parts of France to prevent collaboration between the two groups. The final tables still contained errors due to both calculation and the process of setting the table into type.
- ♦ The teacher describes the need for de Prony's team to efficiently evaluate functions such as sin(x) = x – 1/3!x_ + … for x=0°, 0.1°, 0.2°, … 90°. Then a calculation without fractions is tackled for a practical first experience. Consider the evaluation of 41+x+x_+x_ for x=0,1,2…50. First, each student calculates the whole expression individually and reports the result to be put on the board. Saratoga student results were accurate through x=5; the time required became longer as x increased, taking around a minute for x=5; for x=6 we saw our first errors – the complexity had reached a threshold. The students formulate some estimate of the long time required to individually evaluate the expression through x=100 and the likely accuracy of the results.
- ♦ Adam Smith's description of division of labor is read. Saratoga students found the individual choices and sacrifices necessary to increased productivity by specialization pertinent to choices they face in their near future beyond high

[24] Williams, Michael. *A History of Computing Technology.* Los Alamitos: IEEE Computer Society Press, 1997.
[25] Smith, Adam. *An Inquiry Into the Nature and Causes of the Wealth of Nations.* Available from The Adam Smith Institute at http://www.adamsmith.org/smith/won-intro.htm.

school. A student question of "Can the division of labor be applied to improve productivity of our calculations?" arose out of this experience and we slept on it.

- The intent for this day is that the history content stirs in the student her feelings of enthusiasm or love for people and their relationship with computers, e.g., caring for the lives of sailors which depend on accurate tables, or empathizing with de Prony and his formidable challenge. These feelings enter and permeate her will that is then raised to activity and engaged by the calculations, which are done manually using paper and pencil. Through the experienced need to improve productivity her will stirs her thinking. An imaginative recollection of the facts stir her feelings in relation to the question of how could a team of people, working in the manner described by Adam Smith, do better? These feelings are the fundament needed for the next step.

Overview of content for Day Two.

- The intent for this day is that following sleep, pictures are present and available to the thinking concerning a manufacturing assembly line of people. The next activity fulfills this imaginative rehearsal.
- The students form teams of 3 people each. Each team chooses a city of France for their location. The teacher, playing the second echelon, assigns job descriptions and a work flow to each member of each team, starting the computation at x=3 to avoid job-complicating initial conditions that don't require all three team members:
  - Person 3 must write the value of x on a slip of paper, add 6 to their last result (using 8 for x=3) and pass the slip to person 2.
  - Person 2 must add this input to their previous total (using 11 for x=3) and pass the slip to person 1.
  - Person 1 must add this input to their previous total (using 55 for x=3); if a comparison of the result with the checkpoint sheet shows a discrepancy then the process must be halted and a resolution found, else the result is stacked up.
  - An accuracy check is performed for x=3,4,5,6,7,8 from earlier calculations by individuals. The teacher as second echelon issues the checkpoint sheet showing the values of the function for x=10,20,30,40,50. Checking discrepancies can be a significant task because a problem at the checkpoint for x=20, say, could have arisen at x=19,18,17,16,15,14,13,12, or 11. Each team evaluates the function for x=3,4,5, ….. 50.
- Saratoga students faster teams reached x=50 comfortably within the 45 minute period. A few teams became bogged down with discrepancies. The students made the following observations:
  - High speed of calculation compared to individual effort.
  - Low skill requirement (just adding) per third echelon individual.
  - Opaqueness of the underlying method to the third echelon individuals; only the second echelon and first echelon know what is going on. The accuracy achieved by the team was experienced as magical, with strong power from an unknown source. A student question of "How does it work?" arose out of this experience and we slept on it.
- The intent for this day is that the will is first stirred by being entered and permeated with feelings of enthusiasm fostered by working in a team as well as a little light-hearted competitiveness with other teams. The will that is then raised to activity is engaged by active doing with the hands. In turn, through the need to compute accurately the student's will stirs her thinking. Thinking in turn enters her will to give intentionality to the calculations with paper and pencil by her nimble fingers. Following the hands-in work, an imaginative recollection of the facts stirs her feelings in relation to the hands-in work. These feelings are the fundament needed for the next step.

Overview of content for Day Three.

- The intent for this day is that following sleep, pictures are present and available to the thinking. Reflections and discussions are possible that, through inspiration, bring to consciousness in the child the rules that stand behind the observed facts. This is the context within which the teacher presents the method of differences algorithm. Will, which can draw on the precedent of the hands-in work, enters her thinking to form, direct, and connect these thoughts. By deferring until this day the conjoining of concept with the percepts from the previous day, a practice for "living thinking" is cultivated.
- The class sets out to answer the question of "how does the computation work". Saratoga students noted that all the multiplications in 41+x+x_+x_ had been mysteriously converted to additions, but nobody could see into the source of the magical power. The teacher explains and names "the method of differences" using a table such as below:

x	41+x+x_+x_	1^{st} difference	2^{nd} difference	3^{rd} difference
0	41	empty	empty	empty
1	44	3	empty	empty

2	55	11	8	empty
3	80	25	14	6
4	125	45	20	6
5	196	71	26	6

♦ Then the table is shown to "run backwards" to effect the computation:

x	person 1	person 2	person 3	3rd difference
2	55 ◄ +	11 ◄ +	8 ◄ +	empty
3	= 80	= 25	=14	6

♦ Saratoga students were already interested in methods of mechanizing the tedium. They identified with the intention behind Charles Babbage's letter to Sir Humphrey Davy, president of the Royal Society, July 3rd, 1822, referring to the third echelon of de Prony's calculating teams:

> "The intolerable labour and fatiguing monotony of a continued repetition of similar arithmetical calculations, first excited the desire, and afterwards suggested the idea of a machine, which, by the aid of gravity or any other moving power, should become a substitute for one of the lowest operations of the human intellect."

A reference to the local consumer electronics store "Babbages" was interesting to Saratoga students.

♦ The historical perspective is given that human computing teams persisted until the 1940s. For example, during the early 1940's, Kay McNulty, a recent math graduate from Chestnut Hill College, was employed along with about 75 other young female mathematicians as a "computer" by the University of Pennsylvania's Moore School of Engineering

Figure: Kay McNulty worked as a computer.

These "computers" were responsible for making calculations for tables of firing and bombing trajectories, as part of the war effort. This exemplifies the oldest dictionary definition of computer as "one who computes", predating references to electronic and mechanical machines. The need to perform the calculations more quickly prompted the development of the ENIAC, the world's first electronic digital computer, in 1946. Kay McNulty Mauchly Antonelli recalls[26] computing in 1946:

> We did have desk calculators at that time, mechanical and driven with electric motors, that could do simple arithmetic. You'd do a multiplication and when the answer appeared, you had to write it down to reenter it into the machine to do the next calculation. We were preparing a firing table for each gun, with maybe 1,800 simple trajectories. To hand-compute just one of these trajectories took 30 or 40 hours of sitting at a desk with paper and a calculator. As you can imagine, they were soon running out of young women to do the calculations. Actually, my title working for the ballistics project was `computer.' The idea was that I not only did arithmetic but also made the decision on what to do next. ENIAC made me, one of the first `computers,' obsolete.

This use of the word computer, for human computer, persisted until the 1950's at which time computing tasks were mechanized and people were redeployed as the first "programmers".

♦ The method of differences is said to be an example of a well defined procedure called an "algorithm", something to be followed up next lesson.

Overview of content for Day Four.

[26] Strauss, Robert Strauss. *When Computers Were Born.* Times Mirror Company, 1996.

- The work of Muhammad ibn-Musa Al-Khowarizmi, 9th century Persian mathematician is reviewed. Given the recent US war with Iraq, facts concerning his teaching work at the Mathematical Institute in Baghdad and our heritage from his work carry a certain poignancy. The origin of the word "algorithm", from the Latin translation of his name as Algorismus, and the origin of the word "algebra", from his book "Kitab al jabr w'al muquabala", are explained.
- A characterization of an algorithm and a form are given, e.g., an algorithm is viewed as a sequence of unambiguous and mathematically defined steps that lead to a result and halts. Its form is thought of as:

  Step 1: Do X.
  Step 2: Do Y.
  Step 3: Do Z.
  Step 4: Halt.

  It is noted that the human computing team operated in this manner, with a well defined halt condition.
- A second example is the grade 2 algorithm for the sequence of steps for vertical addition with carrying, also called the ripple-carry addition algorithm. The students write down the calculation for 56+19=85, first the usual succinct way and then step by step something like the following (styles of presentation vary):

  Step 1: Write down the two numbers. So we write
  ```
    56
  + 29
  ```
  Step 2: Add the rightmost digits, i.e., 6+9=15.
  Step 3: Write down the 5. So we write
  ```
    56
  + 29
     5
  ```
  Step 4: Carry the 1 to the second column. So we write
  ```
    1
    56
  + 29
     5
  ```
  Step 5: Add the carry-in 1 and the two digits in the second place from the right, i.e., 1+5+2=8.
  Step 7: Write down the 8. So we write
  ```
    1
    56
  + 29
    85
  ```
  Step 8: Halt.

  In the context of this familiar and transparent algorithm, it is noted that that there is no permissiveness, no room for creativity. Every addition is to be done the same way. The lively thought process of the algorithm designer has come to rest. Computation proceeds with the interpretation of the finished thought embodied in the algorithm. Such is the character of an algorithm. This second grade algorithm also illustrates the tradeoff compared to 1st grade counting that 2nd grade vertical addition is faster but less transparent as to how it works.
- To enter further into the characterization above we can ask if all procedures are algorithms. Consider the directions for making cheese sauce[27]:

  Step 1: Melt in saucepan 2 tablespoons butter
  Step 2: Stir in until blended 2 tablespoons flour
  Step 3: Stir in slowly 1_ cups milk
  Step 4: When the sauce is smooth and boiling reduce the heat and stir in: 1 cup or less mild grated cheese or diced processed cheese
  Step 5: Season the sauce with _ teaspoon salt, 1/8 teaspoon paprika, a few grains cayenne, (1/2 teaspoon dry mustard)
  Step 6: Stir the sauce until the cheese is melted.

  Using the characterization above: sequence of steps – yes; unambiguous steps – no; mathematically defined steps – no; lead to a result – yes; halts - yes. Overall, not an algorithm. Other examples such as changing a car tire are used to bring out the exacting narrowness and high degree of will in thinking required to create an algorithm.
- With the distinctive character of algorithms in mind we can consider one possible characterization of "computing" as the development and analysis of algorithms and means for interpreting them.[28]

[27] Rombauer, Irma S. and Becker, Marion Rombauer. *The Joy of Cooking.* The Bobbs-Merrill Company, Inc., 1953. Page 430.

- The intent for this day is that the history content stirs in the student her feelings of admiration or appreciation for Muhammad's achievements. These feelings enter and permeate her will that is then raised to activity and engaged by the vertical addition calculation. Activity of limbs further stirs the will. Through the need to distinguish the steps in the addition her will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers in the physical layout of the steps. Following the hands-in work, 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.

Overview of content for Day Five.

- The intent for this day is that 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 general rules that stand behind the observed examples of algorithms. This is the context within which the teacher presents the concept of a well-designed algorithm. Will, which can draw on the precedent of the hands-in work, enters her thinking to form, direct, and connect these thoughts. By deferring until this day the conjoining of concept with the percepts from the previous day, a practice for "living thinking" is cultivated.
- So, reflecting on the method of differences and the vertical addition algorithm we ask what we should look for in a "well designed" algorithm. Computer scientists, programmers, and systems analysts are concerned with the development of well-designed algorithms. It must have the characteristic attributes as above. What other attributes would be desirable? This is likened to evaluating a car, e.g., it must have an engine, and it is desirable to be fuel-efficient. Students attributes for a well-designed algorithm are listed:
  - Must-have attributes:
    1. Sequence of steps. (Specific order.)
    2. Unambiguous steps. (Unlike seasoning with a "few" grains of cayenne.)
    3. Mathematically defined steps. (Prerequisite to mechanization.)
    4. Lead to a result. (Definite outcome.)
    5. Halts. (E.g., a procedure for calculating pi exactly would not.)
  - Desirable attributes:
    6. Suggestive name.
    7. Correctness. (The outcome is correct for the problem being solved.)
    8. General. (E.g., addition works for any two numbers.)
    9. Easy to understand. (For maintenance and programming.)
    10. Efficiency. (Fewest steps => minimum time taken to compute measured as a function of the size of its input. Often, there is a tradeoff: maximum speed is sacrificed for greater ease of understanding or vice versa.)
- Efficiency seems like an important attribute, e.g., if the compute time were to exceed one's lifetime that could be disappointing. So we turn to the study of algorithm efficiency.

Overview of content for Day Six.

- This exercise draws heavily on the work of V.W. Setzer and F.H. Carvalheiro.[29]
- A motivation for sorting algorithms is developed. For example, Saratoga students used a start up business scenario. Suppose we want to provide a competitive directory assistance service in New York. A profitable differentiating service is projected to be fast reverse look up by telephone number to find a person's name and address. From a supplier we could buy 20,000,000 records ordered alphabetically by personal and business names. We would need to sort them by order of telephone number to yield a list to be used for our fast reverse lookups. How long would it take to sort the 20,000,000 records? Suppose we wanted then to expand to a nationwide service using multiple 100,000s of records?
- Students organize into pairs for this exercise, both for a warming social interaction and for a helpful separation of concerns in the task. Each pair creates 8 slips of paper from one writing sheet. On each of 8 slips of paper one partner writes a counting number. Exactly 8 numbers is not essential. However, a small number is chosen so the units of work had manageable complexity and a power of 2 simplifies later discussion of binary merge sort. Then the other partner places them one at a time in a row, counting numbers face down, in a random order

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[28] I am using "computing" as a synonym for "computer science". I am not using "computer science" because the word suggests formalism that does not belong in high school.

[29] 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.

while the writer does not look. Now neither partner knows the order of the 8 numbers. The task is set by the teacher as finding, writing down, and naming an approach to rearranging the slips in order of value increasing from left to right subject to the following constraints:

- You can look at the number on at most 2 slips at a time.
- You must forget the contents of a slip after it is placed face down.
- You can compare 2 lifted strips, determining which contains the smaller number.
- You can exchange two strips in position.

While the focus is on algorithm development independent of computing machine, a brief justification for these otherwise arbitrary constraints is given by reference to electronic computer memory locations and processor functions, e.g., they derive from the form of CPU instruction for comparing or exchanging memory location contents that can reference just one memory location in addition to the accumulator.

- ♦ The students are asked to do multiple runs to satisfy themselves that their algorithm works for any configuration of their 8 numbers. Then each pair of students is asked to conduct a sterner test by handing over their written algorithm to another pair to see if the other pair can successfully interpret the algorithm without any subsequent help from the authors. This gives an opportunity for the social experience of teamwork where one's peers are objectively evaluating one's work. Refinements of each write up are made so as to satisfy the must-have attributes of an algorithm. The Saratoga students found significant challenge in the sharp focus and perseverance needed to work through to an algorithm.
- ♦ The intent for working with the soul capacities of a student for this day is as follows. Through the warmth of teamwork and by active doing with their hands the will is stirred. Through the need to figure out how to order the numbers the student's will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers, e.g., are the numbers actually becoming sorted?

Overview of content for Day Seven.

- The mutual testing is completed. Saratoga students were impressed by the fact that testing and refinement took as long as the original development of something that seemed to work. The students thought that testing by other people was a sound discipline but even that was not proof of correctness. However, the prospect of systematically checking every possible configuration of numbers seemed daunting.
- Following testing, the students count the number of comparisons and exchanges for two runs: for the slips in random order and for the slips to be in exactly the reverse order. The measurement of comparisons and exchanges is completed and tabulated. How to scale up to a "large" number, say 20 million numbers, becomes a student question. A general way to quantify the operations is required.
- The intent for working with the soul capacities of a student for this day is as follows. By active doing with their hands the limb activity stirs the will. Through the need to figure out how to order the numbers the student's will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers, e.g., are the numbers becoming sorted? Following the hands-in work, an imaginative recollection of the facts stirs her feelings in relation to the hands-in work. These feelings are the fundament needed for the next step.

Overview of content for Day Eight.

- The intent for this day is that, following sleep, pictures are present and available to the thinking. Reflections and discussions are possible that, through inspiration, bring to consciousness in the child the algorithmic rules that stand behind the observed facts from the first two days. This is the context within which the teacher presents the concepts of algorithm analysis. Will, which can draw on the precedent of the hands-in work, enters her thinking to form, direct, and connect these thoughts. By deferring until this day the conjoining of concept with the percepts from the previous two days, a practice for "living thinking" is cultivated.
- At this stage, either the student's actual algorithms are analyzed or "well-known" algorithms that match or are close to the student's algorithms are introduced to simplify the analysis. This choice would seem to be highly dependent on the level of interest, will, and algebraic ability of the students. Saratoga students created algorithms that were bubble sort, selection sort, a mix of bubble sort and selection sort, or a mix of binary merge sort and bubble sort. Assuming the choice is to work with "well-known" algorithms, the teacher proceeds to a calculation of operations. Hybrid algorithms are analyzed by students depending on their level of interest. In the manner described by Setzer et al[30] the well-known algorithms are analyzed for their number of comparisons and exchanges for a variable number N of items. For N=8 the results are compared with the student counts - they should be comparable. For large N, such as 20M, the order of magnitude comparisons and exchanges are found, e.g., ~10**14 for 20M comparisons needed by bubble sort, ~10**9 for 20M comparisons for binary merge sort. Such order of magnitude calculations call upon feeling in thinking.
- A lower bound for compute time is found with a method such as:
  CPU execution time = clock cycles/instruction x seconds/clock cycle ~ 10 x 1/1Ghz, say ~ 10**-8 s/instruction
  So for ~10**14 instructions we have ~ 20 days and for ~10**9 instructions we have ~5 seconds.
- For an arbitrary large N, order of magnitude results are derived such as bubble sort and selection sort comparisons = O(N_) and binary merge sort comparisons = O($N\log_2 N$). The Saratoga students used the ration for N=200M records to N=20M records. This showed that the bubble sort and selection sort compute times were impractical and the binary merge sort is necessary.
- The next step is announced: to express our algorithm in a programming language for insertion into and interpretation by a computing machine. Reflection on the significant intellectual effort expended so far clarifies the distinction between <u>what</u> the computing machine is instructed to do distinct from <u>how</u> it is so instructed. The algorithm is seen as the bearer of the person's intention of the task and this highly creative work has now come to rest. Subsequent steps must, as faithfully as possible subject to machine limitations, carry out this intention.
- Programming is now introduced. This activity is positioned as already the third of a sequence of software development lifecycle steps: problem definition -> algorithm development and analysis -> programming. The role of the programming language is only a syntactical role – the semantic content is pre-determined by the algorithm. Saratoga students used the Microsoft Q Basic language. Although a programming lesson is not further outlined here, it is recommended that students experience socially oriented parts of the software process, e.g., test or upgrade each other's programs, to balance the soul experience.

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[30] 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.

5. 10^{th} grade: how have computing machines and their relationship with people evolved?

A "day" here happens to be a double 45 minute class – the 10th grade Saratoga students had 2 such distinct classes per week. Double periods worked well for this hands-in course, allowing sufficient time to set out the materials and tools, time to do the work, and time to put away. Twice per week worked well in terms of a rhythm of working with sleep across the two days of each week. Each topic below except the transistor circuits was confined to one week.

Outline of lesson plans.

- Day One
  - History thread: mental math, finger math, and motivation for the abacus
  - Computing machine thread: build an abacus from clay.
- Day Two
  - Computing machine thread: operate the abacus.
  - Computing machine thread: find limitations of the abacus.
- Day Three
  - History thread: John Napier
  - Computing machine thread: build Napier's rods from wood.
- Day Four
  - Computing machine thread: operate the rods for multiplication and division.
  - Computing machine thread: find limitations of the rods.
- Day Five
  - Computing machine thread: operate the rods for square root and cube root.
- Day Six
  - History thread: Baron de Prony's human computing teams.
  - Computing machine thread: experiencing being a human computing team.
  - History thread: what happened to human computing teams?
- Day Seven
  - History thread: Henry Morse and the first telegraph
  - Computing machine thread: build and operate a telegraph circuit.
- Day Eight
  - History thread: George Boole.
  - Computing machine thread: build AND, OR, NOT, NAND, NOR gates from DC components.
- Day Nine
  - History thread: Bardeen, Brittain, Shockley and the transistor.
  - Computing machine thread: build AND, OR, NOT gates from transistors.
- Day Ten
  - Computing machine thread: introduction to binary arithmetic
  - Computing machine thread: combine gates into NOR gates and then into half adder circuits.
- Day Eleven
  - Computing machine thread: combine circuits into a 2-bit adder.
- Day Twelve
  - Computing machine thread: electronic calculators and their limitations.
- Day Thirteen
  - Computing machine thread: electronic calculators and their limitations.
  - Analysis of the trends in how people relate to computing machines throughout history

Overview of content for Day One.

- Begin with an imagination of the paperless world of ancient Egypt, where only a privileged few had papyrus, and before. Math could be done mentally. Do a few exercises to show how calculations soon become difficult, e.g., 989+989 might be of interest for a commercial transaction but is difficult to do mentally. How can we find help? Fingers were a first step to externalizing the arithmetic. Show various representation schemes, e.g., one hand can show up to 9 or up to 99 depending on the scheme.[31] Show Roman counting. Unary at first. Then something special happens at 5 that is resonant with the human hand – V is used, based on the thumb opposed to the four collected fingers. Then something special happens at 10 that is resonant with the human hand – X is used, consisting of two V's. In this way, a 10's representational system is based on 2 hands. A 20's counting system, evidence of which remains in the French vingt, quatre vingt, quatre vingt dix, includes the toes. This relationship to the form of the human being is referred to for each computing machine design until we arrive at binary systems where a non-human basis is used.
- How can we free up our fingers to do other things while the computation is proceeding? Enter the abacus. The students work in pairs for a warming teamwork connection to build a clay tablet and 81 counters. One partner cuts a _" slice from a 6"x6" block of clay, rolls it to a _"x7_"x7_" tablet and scores it with 9 parallel grooves. The teacher cuts one or more slices for the counters, rolls to a _" sheet and divides among the other partners to cut 81 clay cubes per pair for counters.
- The intent for working with the soul capacities of a student for this day is as follows. The will is first stirred with active manual work for the finger math. Teamwork for the clay work creates enthusiasm that, together with associated limb activity, further stirs the will. Through the need to figure out the correct construction of the clay tablet and counters the student's will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers to form the clay. Following the hands-in work, an imaginative recollection of the facts stirs her feelings in relation to the hands-in work. These feelings are the fundament needed for the next step.

Overview of content for Day Two.

- The intent for this day is that, following sleep, pictures are present and available to the thinking. Reflections and discussions are possible that, through inspiration, bring to consciousness in the child the rules that stand behind the observed form from yesterday. This is the context within which the teacher presents the concepts of computing using the abacus. Will, which can draw on the precedent of the hands-in work, enters her thinking to form, direct, and connect these thoughts. By deferring until this day the conjoining of concept with the percepts from the previous day, a practice for "living thinking" is cultivated.
- The teacher shows how to represent numbers on the abacus, with up to 9 counters per groove. The largest number representable per tablet is 999,999,999; the smallest number is 0. The word capacity is introduced for this range. Later exercises can introduce a decimal point, marked with an x in the clay to fix it, and change the capacity.
- The sum 989+989 is redone on the abacus. There are so many counters that mistakes tend to occur. A "second generation" of abacus is created by representing 5 in a special position, namely between grooves - the form of the human hand is being played out. We redo 989+989 to confirm the "upgrade" is working. Students make observations, e.g., faster to manipulate the counters and faster to read the result.
- Now the number of counters has been reduced, the tablet can be made physically smaller. A "third generation", smaller, tablet is created by cutting the still soft tablet in half – each student now has one. The counters are shared out. Already we have experience a trend to pervasive, smaller, less expensive, and faster computers.
- Do many calculations. There are a variety of algorithms (there is no need to use this word) for the arithmetic.[32]
- Is the smaller tablet "computationally as large"? The capacity is found to be the same. Physical size and computational size are separable. How could the capacity be changed? Do 500,000 x 2 that leads to overflow. The end result of moving the counters for this computation is to register 0. (Some electronic calculators do this.) To register the 1 in 1,000,000, we could add a finger, a 10th groove, or place two tablets side by side for 18 grooves to create an enormous expansion in capacity. Students can calculate how large is the expansion in capacity for just doubling the physical size. This is the 4th generation machine.
- What is the essence of the function that the abacus performs for the person? Saratoga students came to the opinion that it is a memory aid, storing interim and final results – the person is doing all the computation. When compared with the activity of mental arithmetic, this machine relieves the thinking and the fingers of any burden of memorizing results.
- Analogies are made to memory, processing, and data input/output in a modern electronic computer - this is preparing the way for an explicit treatment of stored program control in 11th grade.

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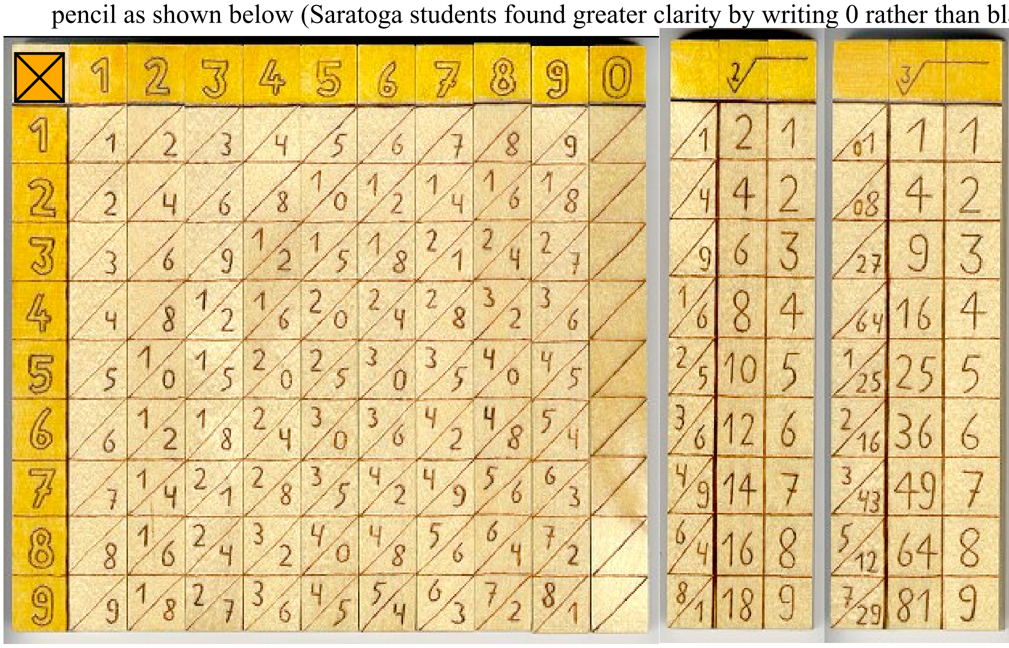
[31] Williams, Michael. *A History of Computing Technology*. Los Alamitos: IEEE Computer Society Press, 1997.
[32] Dilson, Jesse. *The Abacus: A pocket computer*. New York: St. Martin's Press, 1994.

- ♦ Transparency of operation (how easily can an individual understand the operation), power (speed and scope) of operation, limitations of operation (capacity and precision), and extent of human delegation (e.g., memory, processing, ….) are summarized.
- ♦ There are no surviving clay abaci. Various designs in other materials are considered, e.g., Greek marble table, metal Roman abacus, and wooden Chinese and Japanese abaci. The teacher describes how abaci are used today in businesses and schools in China and Japan.

Overview of content for Day Three.

- ♦ John Napier, born in 1550, was a Scottish baron who did math as a hobby. In the late 16th century advances in astronomy were hampered by laborious calculations. Napier took this up as his concern: "The difficulty and prolixity of calculation, the weariness of which is so apt to deter from the study of mathematics, I have always, with what little powers and little genius I possess, laboured to eradicate."[33] His influential book Rabdologia (from the Greek words "rhabodos" and "logos" for "stick reasoning") was published in 1617 shortly after his death.
- ♦ Each student cuts from a strip of wood a set of 13 rods, e.g., 11 rods _"x5" and 2 rods 1_"x5", and marks them in pencil as shown below (Saratoga students found greater clarity by writing 0 rather than blanks):



- ♦ The intent for working with the soul capacities of a student for this day is as follows. The history content stirs in the student her feelings of enthusiasm for John Napier and his intention for reducing the burden of computation for others. These feelings enter and permeate her will that is then raised to activity and engaged by active doing with her hands to cut and mark the rods; the limb activity further stirs the will. Through the need to figure out the correct way of cutting and marking the rods, which is somewhat subtle for a 10th grader, the student's will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers.

[33] A translation by Mark Napier, a descendant of John, of a Latin letter of dedication to Alexander Seton appearing in the introduction to Napier's *Rabdologia.*

Overview of content for Day Four.

- A graduated set of multiplications is done, e.g., 7x4, 71x4, 713x4, 7136x4, … and 713,652,408x4. What is the essence of the function that the rods perform for the person? The machine evidently embodies the multiplication tables to enable the conversion of x to +, provided one number is single digit.
- A graduated set of multiplications for multiple digits is done, requiring the person's memory, or paper and pencil, as an aid.
- A graduated set of divisions is done, using the rods "backwards".
- A decimal point is introduced into one of the numbers, e.g., 7.1x4, 71.3x4, 71.36x4.
- As for the abacus before, the capacity is determined. The unnecessary restriction of one rod per digit is acknowledged. The capacity is seen to be 9999….999 according to the number of 9 rods available; the machine is readily extensible such that the rate of growth of computational capacity far exceeds the rate of growth of physical size.
- The property that the machine does not overflow is identified, since the largest number to be registered, e.g., 999,999,999x9, is accommodated within the cells.
- The $\sqrt{\ }$ and $\sqrt[3]{\ }$ rods are operated[34]. The answers for simple cases are correct. The Saratoga students asked "How do they work?" and we slept on the question.
- The intent for working with the soul capacities of a student for this day is as follows. Will is raised to activity and engaged by active doing with her hands to manipulate the rods. Through the need to figure out the properties of the rods, the student's will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers.

Overview of content for Day Five.

- The intent for this day is that, following sleep, pictures are present and available to the thinking. Reflections and discussions are possible that, through inspiration, bring to consciousness in the child the rules that stand behind the observed form from yesterday. This is the context within which the teacher presents the concepts of how to calculate square roots using Napier's rods. Will, which can draw on the precedent of the hands-in work, enters her thinking to form, direct, and connect these thoughts. By deferring until this day the conjoining of concept with the percepts from the previous day, a practice for "living thinking" is cultivated.
- An explanation of the process underlying the operation of the $\sqrt{\ }$ and $\sqrt[3]{\ }$ rods is given. More difficult problems are solved.
- The rods are raced against the abacus for fun and to investigate relative power.
- Analogies are made to memory, processing, and data input/output in a modern electronic computer - this is preparing the way for an explicit treatment of stored program control in 11th grade.
- Transparency of operation (how easily can an individual understand the operation), power (speed and scope) of operation, limitations of operation (capacity and precision), and extent of human delegation (e.g., memory, processing, ….) are summarized.

Overview of content for Day Six.

- The treatment of human computing teams is the same as for the 11th grade history thread and computing machine thread for that topic in Section 4 above. The underlying algorithm is deferred to grade 11.
- Saratoga students were highly enthusiastic about this activity. They were highly impressed by the productivity gain over individual effort due to division of labor.
- Transparency of operation (how easily can an individual understand the operation), power (speed and scope) of operation, limitations of operation (capacity and precision), and extent of human delegation (e.g., memory, processing, ….) are summarized.

Overview of content for Day Seven.

- The teacher gives the story of Samuel Morse and the electric telegraph. He was also a painter and sculptor. Saratoga students enjoyed examples of people with broad interests and skills – each of us could find an affinity with such a person. A focus is brought to the transition from a 10 state system, fashioned after the human hand, to a 2 state system characteristic of electrical circuits.

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[34] Some worked examples are available at http://www.qnet.fi/abehr/Achim/Calculators_Napier_rods2.html.
A complete explanation of the algorithm is given in Schuberth, Ernst. *Introduction of Advanced Arithmetical Operations for Waldorf School 7th Grades. The Calculation of a Square Root and Higher Roots.* Fair Oaks: AWSNA, 1999.

- The teacher builds one circuit, placing a battery and wires with alligator clips that is used to close the circuit in the remotest point in the classroom. Long wires run to a buzzer among the student body. This circuit is shown to be analogous to the telegraph circuit used to send Samuel Morse's first message from Washington D.C. to Baltimore in 1844. The single abstraction of a schematic is handed out and discussed.
- The teacher hands out a Morse Code alphabet and demonstrates signaling. Signaling is done by opening and closing the contact between two alligator clips. It is pointed out that printed dots and dashes preceded audible long and short sounds. To train the students to translate from sound, the teacher signals SOS (no spaces between the letters so does it really stand for Save Our Souls?) and Morse's first message "What hath God wrought." The students take turns signaling to the others students who write down the message. Saratoga students enjoyed this social experience.
- It is examined closely how long strings of dots and dashes arise from the need to use 2 symbols to differentiate 26 letters, 10 digits, and various symbols of punctuation.

Overview of content for Day Eight.

- The teacher tells the story of George Boole and Claude Shannon. Their diverse individual talents provide interest. In 1854, Boole published laws of logic in the form of an algebra.[35] We remember him whenever we use "AND, OR, and NOT" to connect search terms to find information in search engines. Boolean algebra was largely unknown and unused until 1938 when Claude Shannon published an article based on his master's thesis at MIT that showed how Boolean functions can be used to represent the functions of switches in electronic circuits. Shannon had provided electronics engineers with the mathematical tool they needed to design digital electronic circuits, as the students are soon to do.
- The students are organized into pairs for a warming social component and to help each other think through making circuits. The teacher explains the first exercise is to build a circuit to be used to manually turn a bulb on and off, and demonstrates the circuit. There is no intention here to volunteer how the components work – the 11th grade electricity and magnetism block could do that – just to demonstrate the behavior phenomenologically. The teacher hands out a physical diagram for the circuit with a component list (e.g., 1 double battery holder, 2 AAA batteries, 1 bulb holder, 1 bulb, 1 5 ohm resistor, 4 jumper leads). The student pairs pick up their components and make the circuit work as was explained and demonstrated. The class gathers in attention to be sure everyone thoroughly understands what they have done. A schematic for the circuit is handed out and the interpretation and usefulness of this abstraction discussed.
- The teacher explains the AND function, hands out a physical diagram for the circuit with a component list (1 more jumper lead). The student pairs pick up their components and figure out how to make the circuit work with this "and" condition. The class gathers in attention to be sure everyone thoroughly understands what they have done. A schematic is handed out and discussed.
- The teacher states the intention to do arithmetic with a combination of logic gates, by achieving the needed behavior. The students are asked to be patient to wait see this happen. To be able to express circuit behavior we need a vocabulary – the table below is handed out, and its contents compared with the observed And circuit behavior:

Switch A closed	**Switch B closed**	**Light on**
True	True	True
True	False	False
False	True	False
False	False	False

  The term "truth table" is introduced.
- In a similar manner, OR, NOT, NAND, NOR gates are built, physical diagrams, schematics, and truth tables studied. The students make at least one of these circuits from the teacher's verbal description, and not rely on handouts, so as to further internalize the disciplines.
- The exercises on this day introduce much new content for the students but with familiar physical components. This new content can now be carried into work with transistors that are a new and impenetrable technology for students this age.

Overview of content for Day Nine.

- The teacher gives some history of the invention of the transistor in 1947 by Bardeen, Brattain, and Shockley at Bell Laboratories in New Jersey.

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[35] Boole, George. " An Investigation Into the Laws of Thought, on Which are Founded the Mathematical Theories of Logic and Probabilities." in Classics of Mathematics, Ronald Calinger, ed. New Jersey: Prentice Hall, 1995. Pages 95-96.

- ♦ The students are organized into pairs for a warming social component and to help each other think through making circuits. The teacher explains the first exercise is to build a circuit to be used to manually turn an LED on and off, and demonstrates the circuit. There is no intention here to volunteer how the components work, just to demonstrate the behavior phenomenologically. When Saratoga students asked questions I described the materials and a summary of the behavior in context of other components. The teacher hands out a physical diagram for the circuit with a component list (e.g., 1 breadboard, 1 4.5V power supply, 1 LED, 1 1500 ohm resistor, box of jumper wires). The student pairs pick up their components and make the circuit work as was explained and demonstrated. Some LEDs blow out because the resistor is not connected in series. The class gathers in attention to be sure everyone thoroughly understands what they have done. A schematic is handed out and the interpretation and usefulness of this abstraction discussed. A truth table is derived through class discussion.
- ♦ The teacher explains the second exercise is to build a circuit to use a transistor as a switch, and demonstrates the circuit. There is no intention here to volunteer how the transistor works, just to demonstrate the behavior phenomenologically. The teacher hands out a physical diagram for the circuit with a component list (1 more 1500 ohm resistor and a transistor). The student pairs pick up their components and make the circuit work as was explained and demonstrated. The class gathers in attention to be sure everyone thoroughly understands what they have done. A schematic is handed out and the interpretation and usefulness of this abstraction discussed. A truth table is derived through class discussion.
- ♦ The teacher reminds everyone of the AND function, hands out a component list, physical diagram, schematic, and truth table for the circuit. Each pair builds the circuit. Those who finish first can help those struggling.
- ♦ Similarly, OR and NOT are implemented. The circuits are labeled with the owner’s names. 3 ANDs, 7 ORs, and 6 NOTs, are required for a 2-bit adder.

Overview of content for Day Ten.

- ORs and NOTs are combined pairwise into 6 NORs. The change of symbol for the schematic is noted. The ownership of circuits is combined. Student pairs are now relying on the correctness of the circuits by other student pairs for the combination to work.
- The teacher reminds everyone the intention is to do arithmetic with these circuits even though how to do so accurately is mysterious so far. The teacher gives an introduction to the binary representation of numbers, works through exercises in addition of 1-bit numbers, and translates the truth tables so far into 1 and 0 format. A Boolean function operates on one or more inputs, producing an output. Each of the inputs and the outputs can have one of 2-states. These 2 states can be expressed as true and false or equally well as 1 and 0. By choosing 1 and 0 we can do arithmetic functions.
- The students are asked as a class for suggestions to help construct a truth table for a circuit that, if we could build it, would perform addition of two 1-bit numbers, e.g.

Input switch A closed	**Input switch B closed**	**Red LED on**	**Green LED on**
1	1	1	0
1	0	0	1
0	1	0	1
0	0	0	0

The class is now working out of this shared intention.

- The teacher demonstrates how 2 NOR circuits and 1 AND circuit are combined to implement the needed truth table. This circuit is called an "adder" – it is conventionally called a "half adder" but that name might seem confusing at this stage.
- The block diagram is introduced and the higher level of abstraction than the earlier schematics acknowledged.

Overview of content for Day Eleven.

- The students combine NOR and AND circuits into 3 adders.
- The students are asked as a class for suggestions to construct a truth table for a circuit that, if we could build it, would perform addition of two 2-bit numbers, e.g.

Input switch A closed	**Input switch A closed**	**Input switch F closed**	**Input switch F closed**	**Yellow LED on**	**Red LED on**	**Green LED on**
1	1	1	1	1	1	0
1	1	1	0	1	0	1
:	:	:	:	:	:	:
0	0	0	0	0	0	0

The class is now working out of this shared intention.

- The teacher demonstrates how 2 adder circuits and 1 OR circuit are combined to implement into a larger circuit (conventionally called a "full adder") that when combined with an adder gives the desired behavior. Saratoga students built exactly 3 ANDs, 7 ORs, and 6 NOTs so we concluded with the delightful situation that for the 2-bit adder to work then each individual circuit must work and they must be correctly combined. Everyone was relying on everyone else's contribution and working together to make the whole functional.
- If the students are ready, the extensibility to a 3-bit adder and so on using multiple full adders is outlined.
- Analogies are made to memory, processing, and data input/output in a modern electronic computer - this is preparing the way for an explicit treatment of stored program control in 11th grade.
- A concluding perspective on transistors is given. Transistors have been made smaller, increasingly dense in their interconnection, and as a consequence of both developments also faster, cheaper to make, and cheaper to run. Interconnection of transistors was historically done at first using wires just like the work done with the students, then on a circuit board whereon are mounted discrete transistors plus wiring deposited on the board, then by an integrated circuit wherein multiple transistors and their linkages are manufactured onto a single chip of silicon. A well known chip, such as the Pentium, is described in terms of millions of transistors. Moore's Law is characterized. All these stages of evolution are exemplified with physical examples.

Overview of content for Day Twelve.

- Electronic calculators are identified as being composed of circuits like the adders just constructed.

- Detail is given here for an exercise with calculators. A practical issue arose in the Saratoga class in that many students could not properly input exponents; the syntax for that operation had to be understood for each type of calculator before the intended exercise could be launched.
- Half the class is asked to calculate [(3 + 9x10**-20) - 3] x 10**21 – 3, yielding –3.
- The other half is asked to calculate [(3 – 3) + 9 x 10**-20] x 10**21 – 3, yielding 87.
- The students are asked to compare the two expressions, and they are found to be equivalent; further, as can be computed even mentally from the second expression, the correct result is 87.
- The two halves of the class are asked to swap calculations. The same, wildly different, results occur. Saratoga students were perturbed and asked "why?" Faulty calculators cannot satisfactorily explain this phenomenon if there is a diversity of products. Faulty input by the operator would be unlikely to yield such consistent bimodal results. Saratoga students became more urgent with their question – the trusty calculator was behaving in a crazy manner.
- The intent for working with the soul capacities of a student for this day is as follows. By active doing with their hands, with both the calculator and paper and pencil, the limb activity stirs the will. Through the need to figure out the crazy results the student's will stirs her thinking. Thinking in turn enters her will to give intentionality to her nimble fingers, e.g., are these results for real? Following the hands-in work, an imaginative recollection of the facts stirs her feelings in relation to the hands-in work. These feelings are the fundament needed for the next step.

Overview of content for Day Thirteen.

- The intent for this day is that, following sleep, pictures are present and available to the thinking. Reflections and discussions are possible that, through inspiration, bring to consciousness in the child the rules embodied by the calculator that stand behind the observed facts from yesterday. This is the context within which the teacher presents the concepts of number representation capacity, precision, and accuracy. Will, which can draw on the precedent of the hands-in work, enters her thinking to form, direct, and connect these thoughts. By deferring until this day the conjoining of concept with the percepts from the previous day, a practice for "living thinking" is cultivated.
- The teacher guides the students to understand the representation of numbers by their machine, e.g., 1+10**-1 = 1.1, 1+10**-2 = 1.01, …., 1+10**-9 = 1.000000001, 1+10**-10 = 1. What happened to the 10**-10? Each calculator has a cut off at roughly this order of magnitude. Saratoga students guessed that limited memory <u>capacity</u> led to this loss of <u>precision</u> of representation of the number.
- Is there a rounding or a truncation? We explore the 10**-10 boundary. We cannot make the desired distinction when the last digit is less than 5, so 1 + 6x10**-9 = 1.000000006 is computed. Next, 1 + 6x10**-10 = 1.000000001 shows a rounding up. Further investigation shows that while the external display shows 1 + 6x10**-10 = 1.000000001 the internal view is 1 + 6x10**-10 = 1.0000000006. This subtlety around internal representation versus external representation could confuse and take the focus off the overall process of truncation. Next, 1 + 6x10**-11 = 1, showing a truncation. This truncation is confirmed to have happened internally as well as externally. The 6x10**-11 has been ignored.
- A step-by-step display of the interim results for each of the two original calculations shows how the loss of precision of representation of the number led to a loss of accuracy.
- How to avoid such loss of accuracy? Well, we can increase precision by increasing the capacity for number representation. While that is helpful to solve known cases, the phenomenon can reappear as numbers arise that incur truncation. We must act decisively through our thinking, specifically through our understanding of algorithms, to "condition" the calculation to be "well-behaved". The students look at a specific practical example in detail. For example, consider an electric power company that calculates the network power loss as the difference between the power sent out into the network minus the sum of the power consumptions of buildings. The latter can be measured by a truck systematically driving the streets using a wireless reader of household meters - a talking point for Saratoga because this technology has just been introduced. After the first 15,000 readings, say, the total might be so high that each individual addition would be truncated, thereby not including the other 15,000 readings. The apparent loss would be huge, with many business and environmental implications. The summation has to be conditioned, e.g., measure each neighborhood and store the number, then as a separate step add the neighborhood totals which are likely to be sufficiently close to avoid truncation.
- Saratoga students felt that the calculator results made sense again, but the calculator could no longer be blindly trusted as before. The calculator had been shown to not embody the commutative law of arithmetic. Aware of the limited precision and its potential affects, the operator must retain responsibility and accountability for those, e.g., the –3 result was precise but inaccurate. Feeling in thinking is required to judge accuracy. This is supported in quantitative work by estimation, e.g., is the kind of number to be expected a small negative number or around 100?

- Transparency of operation (how easily can an individual understand the operation), power (speed and scope) of operation, limitations of operation (capacity, precision, AND accuracy), and extent of human delegation (e.g., memory, processing, ….) are summarized.
- The course culminates with each student summarizing their observation of trends in how people relate to computing machines throughout history:

	Transparency of operation	**Power (speed and scope) of operation**	**Limitations**	**Extent of human delegation**
Abacus				
Napier's rods				
Human computing team				
Electronic adder		X	X	X
Electronic calculator				

X means the cell was not filled out due to insufficient experience.

- For Saratoga students, the nature of the responses were generally along the following directions:

	Transparency of operation	**Power (speed and scope) of operation**	**Limitations**	**Extent of human delegation**
Abacus	Highest	Very low	Many	Least
Napier's rods	High for x and /, low for $\sqrt{\ }$ and $\sqrt[3]{\ }$	Low	Some	High
Human computing team	None for a 3rd echelon person	High	Few	Very high for a 3rd echelon person
Electronic adder	Low	X	X	X
Electronic calculator	Very low	Very high	Few	Very high

X means the cell was not filled out due to insufficient experience.