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Teaching Machines and Teaching Aids in the Ancient World

Abstract

The article examines the developments by the ancient Greeks and Romans of various types of instructional devices, specifically teaching machines and teaching aids. Examples of teaching aids and teaching machines designed by Archimedes, Hero of Alexandria, Quintilian, and others are described and discussed. Teaching machines developed for physical, gladiatorial, and military training are discussed, as well as probable reasons why they were developed further and placed in widespread use. The article presents some of the ancient attitudes and mindsets towards pedagogy, physical training, and military preparation and shows how those desiring to improve contemporary education might benefit from an awareness of the ancient world's approach, treatment, and application of instructional devices.

Résumé

Cet article traite de la mise au point, dans la Grèce et la Rome antiques de divers types de dispositifs pédagogiques et particulièrement de machines et de matériels didactiques. L'auteur décrit et analyse divers exemples de matériels et de machines didactiques conçues notamment par Archimedes, Héron d'Alexandrie et Quintilien. Il traite également de machines conçues pour l'entrainement des athlètes, des gladiateurs et des militaires ainsi que des raisons probables de leur multiplication. L'auteur décrit également certains points de vue et attitudes des Anciens face à la pédagogie, à l'entraînement physique et à la préparation militaire; il montre en quoi le fait de connaître la façon dont les Anciens concevaient l'usage des appareils pédagogiques est plein d'enseignements pour quiconque souhaite améliorer les méthodes pédagogiques modernes.

When the term "teaching machine" is mentioned, most individuals conjure up an image of rows of students seated in front of box-like objects, or students seated in front of some variety of computer terminal. Both images are accurate, but one of ancient Greeks and Romans using mechanical devices both for teaching aids and teaching machines (sometimes referred to as auto-instructional devices) is not one commonly envisaged. A current misconception is that the technology of and the ideas behind teaching machines are products of the twentieth century.

Many contemporary works concerned with teaching machines credit two American psychologists with their invention (Lumsdaine & Glaser, 1960, pp. 6-12; Kay, Dodd, & Sime, 1968, pp. 41-44). The first, Sidney Pressey of Ohio State University, developed a typewriter-like device in the early 1920s, which presented a series of multiple-choice questions. The student responded to each question by pressing a lettered key. The device indicated whether the response was correct or not, and it also kept a record of the number of attempts, both correct and incorrect (Pressey, 1926). The other is B. F. Skinner, of Harvard. During the 1950s Skinner devised an apparatus based on his concept of operant conditioning. The device, unlike Pressey's, presented a series of problems or questions which required written responses. Once a response was written, and the machine advanced, the entered response was shielded from erasure and the answer, hitherto obscured, was revealed. Like Pressey's machine, Skinner's apparatus could keep a record of the students' progress (Skinner, 1961).

Other works, however, state that devices such as globes and orreries (mechanical planetaria) were introduced to teaching during the seventeenth century (Anderson, 1962, pp. 19-21). The prospect of the ancient Greeks or Romans possessing both teaching aids and teaching machines is not even considered. At this point, to provide a clear picture and to reduce the likelihood of confusion, definitions of what teaching machines and teaching aids comprise will be provided.

Operational Definitions

Teaching machines

A teaching machine may be defined as a mechanical, pneumatic, electrical, electro-mechanical, or electronic device which, upon some sort of manipulation (input) by the user, performs some sort of transformation of the input and then provides some recognizable form of instructive feedback. Forms that teaching machines may take include: the simulation of a realistic condition, a dangerous condition, or a situation not readily observable by the user; the tangible manifestation of a theory or a philosophy; the presentation of questions or information followed by questions, with provisions for response and analysis of the response. By this definition, therefore, books, chalkboards, globes, and similar materials are not teaching machines. Computers, however, may be set up to perform as teaching machines. Examples are dedicated personal devices such as "Speak and Spell", and software-driven computer-assisted instruction systems such as "PLATO".

Teaching aids

Teaching aids may be considered to be those items which do not fit the above definition, but which are primarily used to be illustrative or assistive in pedagogy or training. Diagrams, books, and blackboards may therefore be considered teaching aids. The following example may make things clearer. A diagram of the solar system is not mechanical, nor can it accept any form of input which will result in it performing a transformation and presenting instructive feedback. It is therefore not a teaching machine. The diagram may be used by a teacher in a lesson to illustrate the relative position of the planets. In this instance, it is being used as a teaching aid.

Necessary tools

Necessary tools comprise those instruments or devices which are essential in order for that particular activity in education to be accomplished. A violin, for example, is a necessary tool for violin playing. Similarly, a compass or a circle template is a necessary tool for the drawing of true circles in a demonstration of geometry. It is possible to consider necessary tools as teaching aids if they are used for instructive purposes in a subject for which they are not necessary. An example is the use of the violin to demonstrate the principles of harmonics to a physics class. While a violin may illustrate harmonics adequately, it is possible to use other instruments and apparatus to illustrate the concept. In this instance the violin is a teaching aid, not a necessary tool. Bearing these definitions of terms in mind, we are prepared to consider some ancient teaching machines and teaching aids.

Greek Devices

Archimedes' planetaria

While devices that could have been considered teaching machines may have been constructed earlier, the evidence available indicates that Archimedes (287-212 B.C.) produced some of the first. Among the machines he constructed there were at least two that comprised spherical representations of the earth and important celestial bodies and which also, when a mechanism was turned, showed their relative motion. A book by Archimedes entitled *On Sphere Construction* supposedly described both the construction and the application of his devices. The work has not survived, and other accounts must suffice (White, 1984, p. 179). The earliest extensive description of these is provided by Cicero (106-43 B.C.), who not only described them, but discussed their purpose and provided plausible explanations of why they were constructed (*De re publica* , 1. 14. 21-22).

From Cicero's description, it seems that the two were similar in construction, although one was more elaborate than the other. Each consisted of a larger central sphere (representing the earth) and smaller spherical representations of the moon, the sun, the five known planets, and possibly other celestial bodies. (It is important to note that the concept of a geocentric cosmos was prevalent during that time.) How these smaller spheres were supported in relation to the central sphere is not revealed. Upon the movement of a mechanism by the user, the smaller spheres would revolve about the larger, following a path resembling their observed movements through the sky. In addition, the movement of the spheres was relative, so that relative position as well as phenomena such as eclipses would be shown accurately. Cicero's description is cut short abruptly, since several pages of the manuscript are missing. Given this information, it appears that Archimedes' devices were mechanical representations of the cosmos as it was then understood. In many ways, the aforementioned devices appear to be similar in principle to modern orreries (mechanical planetaria). From where did the idea for showing the cosmos in this manner come? Cicero provides an answer.

Thales' globe

Cicero relays information from his friend Gaius Sulpicius Gallus, who describes a globe allegedly constructed by Thales of Miletus (ca. 550 B.C.) which he believed to be a precursor to Archimedes' mechanical representation. According to Gallus, Thales' globe was solid, had several constellations painted on its exterior, and was the first of its kind. It is further stated that the information on the globe was engraved onto it some years later, by Eudoxus of Cnidus. One may infer that the globe had probably been used extensively, so that the paint had worn thin; but its use was still important enough to justify the effort of engraving (*De re publica*, 1. 14. 21-22). This raises another question: For what was it used?

It seems that Thales' celestial globe was intended to show the constellations in much the same way that a modern globe shows the major continents of the earth. Thales' globe, therefore, was probably used for instruction in astronomy. If this is so, the globe may be classified as a teaching aid, since it was used to illustrate the location of stars in the sky. The globe had no means of accepting an input, performing a transformation and then presenting instructional feedback, and so it could not be considered a teaching machine. This observation does not mean that the usefulness of the globe was limited to its being used in conjunction with other forms of instruction. Cicero describes how the poet Aratus, who had no knowledge of astronomy, accurately described the heavens by simply studying the globe. From this account, it is apparent that Thales' globe could impart useful information without coincidental instruction from a lecturer, even though the globe could not simulate the motions of the celestial bodies. Cicero also mentions that the major disadvantage of Thales' globe was that it could not show the motions of the sun, planets, or any other celestial body (*De re publica*, 1. 14. 21-22). Although the globe attempted to simulate the cosmos, the simulation was not complete, since the movement of the planets and the sun could not be reproduced. Why was the study and teaching of the cosmos of such importance?

Instructional applications of Archimedes' planetaria

According to Cicero the study of astronomy, as well as the understanding of the movement of celestial bodies, was necessary for one to obtain the knowledge of the gods. To possess the knowledge of the gods, in Stoic philosophy, was both desirable and encouraged.

> And contemplating the heavenly bodies the mind arrives at a knowledge of the gods, from which arises piety, with its comrades justice and the rest of the virtues, the source of a life of happiness that vies with and resembles the divine existence and leaves us inferior to the celestial beings in nothing else save immortality, which is immaterial for happiness. (*De natura deorum*, 2. 61. 153-154)

It is a logical progression from this premise, that if one could obtain a better understanding of the **heavenly bodies**, one's knowledge of the gods would be more extensive.

If one can learn some information by studying a passive object such as a globe independently, *a fortiori*, an individual could learn even more by being able to interact with a device that would produce recognizable instructive feedback dependent upon the user's input. By manipulating and observing a functional simulation of the cosmos, therefore, the operator could learn how his or her actions caused the **heavenly bodies** to revolve around the earth, each in a peculiar but related manner. In addition, such a simulator could teach the user what was occurring during a lunar eclipse. The idea of showing concepts in a concrete or a tangible way was an important consideration. Cicero noted that it is most difficult for individuals to be expected to believe that which they cannot observe (*De natura deorum*, 2. 37. 93-94). Archimedes' devices were able to demonstrate the idea that the abstract concept of the cosmos of that time was true. Besides transforming an abstract concept into a concrete simulation, Archimedes' planetaria could also show a "god's-eye view" of the layout of the cosmos, as well as showing how the gods could control the movement of the cosmos. Cicero supports these views in his *Tusculan Disputations* where he states, "If that [the movement of the moon and the planets] cannot happen in the Universe without the action of a god, neither could Archimedes have copied those motions on a sphere without divine intelligence" (1. 63-64).

In the ways just described, Archimedes' devices could have been used as teaching machines. The fact that the concept of a geocentric planetary system was later proven to be erroneous does not diminish the validity of the pedagogical principles underlying Archimedes' planetaria. It is unlikely that they were primarily intended for any use other than teaching. It would not have been possible for them to be used as navigational aids, since there was no way of aligning the motion of the devices to any celestial bodies. It is also unlikely that the planetaria were used for predicting eclipses and other astronomical phenomena, since the user, not some form of time piece, had to cause the mechanism to turn. The planetaria were also not considered to be toys or gadgets. It should be noted that Archimedes fabricated the devices sometime before his death in 212 B.C. Cicero wrote his account of the planetaria at approximately 70 B.C., more than 130 years after they had been produced. He describes how they were removed from Syracuse, after its capture by Rome, by Marcellus, and that the more elaborate of the two was placed in the Temple of Virtue where it was observed by many people and became widely known. The other planetarium, the one Cicero describes, was kept privately and was well taken care of (*De re publica*, 1. 14. 21-22).

Schlebecker (1977) describes four essential elements which are required before a technological invention can occur: (1) accumulated knowledge; (2) evident need; (3) economic possibility; and (4) cultural and social acceptability (p. 650). In the case of Archimedes' planetaria, the first element is satisfied, since there was, evidently, more mechanical information available than had been available during the time of Thales of Miletus. Cicero's accounts illustrate that there was an evident need for mechanical representations of the movements of celestial bodies, in order for one to share in divine intelligence. The fact that at least two such devices were produced not only satisfies the second element, but it also satisfies the third and fourth elements. It is apparent that someone paid for the construction of the planetaria and since two were built, with one being quite elaborate, it follows that the cost of construction was not seen to be unrealistically high. In addition, other pedagogues constructed devices similar to Archimedes' planetaria. Such action indicates further support for the fourth element.

Posidonius' planetarium

Posidonius of Rhodes (a Stoic philosopher who had taught Cicero at one time) did make a similar although simpler replica of one of Archimedes' planetaria (*De natura deorum*, 2. 34-35). From Cicero's description, it seems that Posidonius' planetarium operated in the same manner as Archimedes' devices. It is likely, therefore, that the planetarium constructed by Posidonius was used as a teaching machine and possibly as a teaching aid as well.

Antikythera mechanism

A logical progression from a three-dimensional simulation of the cosmos is to show it in a planar fashion. To be sure, simple globes, orreries, and other such devices similar in principle to Archimedes' planetaria have been used and continue to be used for educative purposes. It is important to note, however, that as such devices become more complex in design, providing more information, they also increase in weight and bulk (King & Millburn, 1978).

Evidence that the ancient Greeks encountered and dealt with this problem comes from the preserved fragments of the so-called Antikythera mechanism, which dates from approximately 80 B.C. The remains were discovered, during 1900-1901, in an ancient shipwreck located off the coast of the island of Antikythera, which is situated to the northwest of Crete (Price, 1974, pp. 6-12). The remains, which are badly encrusted and thus obscured, reveal that the device consisted of an array of bronze gears which, when a single drive shaft was rotated, moved several circular engraved bronze plates (Price, 1974). Through extensive cleaning, and by means of radiographic analysis, it appears that two of the engraved bronze plates represented the sun and the moon. Small, evenly spaced marks on the plates suggest that they were intended to show movement by degrees. It also appears that the movement of the plates was in relation to an engraved zodiacal circle (Price, pp. 13-20). A partially legible inscription on the rear rectangular plate seems to be a description of what is represented on the machine. It is also possible that the inscription contains instructions on how to set the apparatus (Price, p. 50). References to pointers, in the inscription, as well as the aforementioned gradations on the rotatable plates, suggest that the machine was intended to show movement accurately. A question that arises at this point is: What was the device used for?

Price (1974) states that the device appears to have been some sort of a hand-held "calendrical Sun and Moon computing mechanism. . ." (p. 13). As to its applications, Price is not certain, since the device is not complete. He also states that the device was not a navigational tool (p. 22). If the

Antikythera mechanism was a portable hand-operated device, then it is possible that it was used as a teaching aid or even as a teaching machine. Price also refers to a critic of his research who contended that the Antikythera device was not ancient, but a modern orrery or a planetarium similar in design to one from which he had learned the fundamentals of the solar system in school (p. 12). Although scientific analysis has shown that the device is ancient, the readily apparent similarity between it and a modern flat orrery supports the contention that the Antikythera mechanism may well have been used for instructional purposes. It is also significant to note that the inscription on the rear rectangular plate implies that individuals could use the device on their own. If use of the mechanism required a trained operator, or an individual with extensive knowledge of calendrical calculation, then the inscription would have been superfluous. If it was possible for an individual to operate the mechanism without constant supervision, then it would satisfy the requirements of being a teaching machine. In addition, the device appears to have been used extensively, since there is evidence of a break and subsequent repair in one gear (Price, p. 28). The evidence of repair also indicates that the Antikythera mechanism was not considered to be a mere gadget or an object for amusement. A paucity of contemporary evidence and information, however, prevents one from establishing conclusively, exactly how the device was used and for what purpose.

Teaching aids continued to be prevalent in the ancient world as well. Examples can be found in some of the devices invented by Hero of Alexandria (probably first or second century A.D.).

Hero's Teaching Aids

Kettle and sphere device

Cicero stated, following a tenet of Stoicism, that he could not be expected to believe something, specifically a philosophical idea, unless he could observe some model or manifestation of it (Brumbaugh, 1966, p. 105). This tenet provides a possible explanation of the purpose of many of Hero's devices. Some appear to be teaching aids specifically intended to embody some demonstration of a philosophical idea. One such aid was the apparatus that was intended to support a small hollow sphere by means of a jet of steam. According to Hero's description, the device consisted of a kettle which was to be filled with water and then placed above a fire. The lid of the kettle was tight fitting and also had a small diameter tube projecting from the middle. A bottomless cup was attached to the top of the tube and the hollow sphere was placed in it (Hero, *Pneumatica*, 2. 6). When the water boiled, the steam escaping from the tube would lift the sphere above the cup and would hold it stationary. Figure 1 (after Hero, *Pneumatica*, 2. 6) illustrates this arrangement.

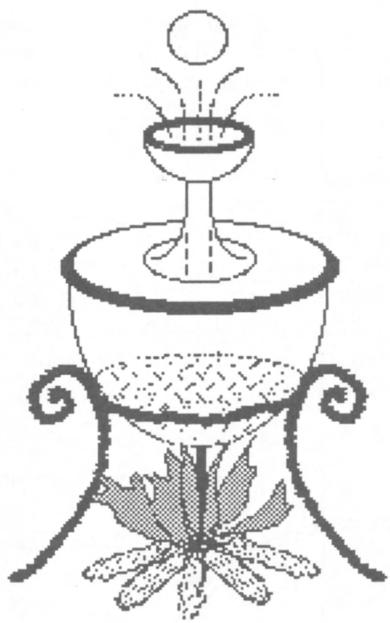

Figure 1.
Hero's teaching aid for demonstrating the power of pneuma

Although we know that aerodynamic forces hold the sphere in position, it is likely that Hero and other contemporaries believed that the suspended sphere represented a simulation of the Stoic concept of the earth being held in place in the cosmos by the gods' *pneuma*. Stoics believed *pneuma* to be a rarefied material which not only supported the earth, but which was also responsible for the position and the order of the celestial bodies. This philosophy was in sharp contrast to that of the Epicureans, who held that rarefied materials could not support a denser object (Brumbaugh, 1966, pp. 105-106). It is entirely possible, therefore, that Hero's device was a teaching aid that was used to illustrate how the earth was supported in the cosmos. This device could not be considered a teaching machine, since there is no user input, save that of lighting the fire under the kettle.

Glass hemispheres device

Hero produced another device, which illustrated further the Stoic concept of the earth supported in the cosmos. The previous apparatus required the use of steam, which is a rarefied material, but in rapid motion. A further proof of Stoic tenets consisted of showing a representation of the earth supported by air that is stationary. In order to accomplish this, Hero devised an apparatus which consisted of two glass hemispheres and a bronze plate. The bronze plate, which was attached to the lower hemisphere, had a hole cut in its centre. The hole's diameter was slightly larger than that of a small hollow sphere which was intended to be placed through the hole. The lower hemisphere was filled with water, and this supported the hollow sphere level with the bronze plate. The upper hemisphere was then placed on top of the bronze plate. Through some means, probably a small spigot in the lower hemisphere, some water was extracted from the assembly. The hollow sphere was intended to remain in position and not to remain on the surface of the water, thus proving that stationary air could support an object of greater density. Figure 2 (after Hero, *Pneumatica*, 2. 7) illustrates the likely appearance of this device.

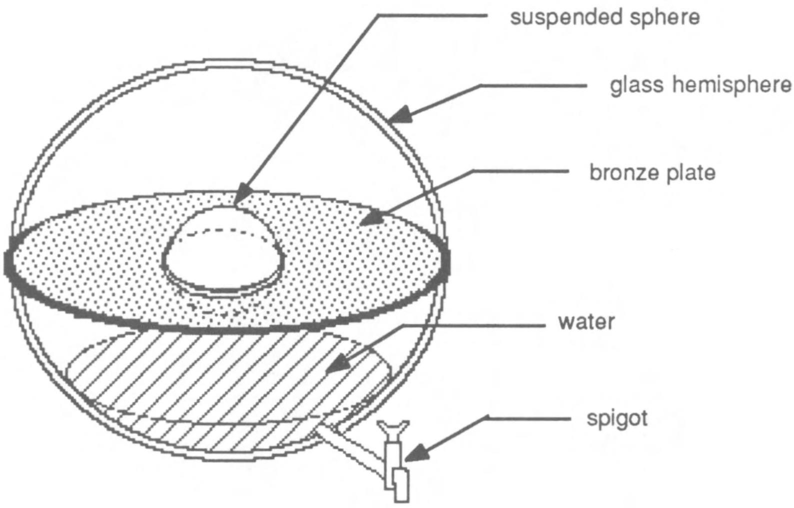

Figure 2.
Teaching aid designed by Hero
to show how stationary air could support a sphere

At first glance it seems highly unlikely that this apparatus could perform such a function, but a modern model of it was constructed by the E. H. Sargent Scientific Company of Chicago, under the direction of Sherrick and Brumbaugh (Brumbaugh, 1966, pp. 89, 106-108). The model functioned just as Hero had predicted. By means of this more elaborate model, it was possible to make a case that stationary air could support a heavier object, although we know now that this was not actually what was happening within the apparatus. Brumbaugh (1966) points out that Hero's glass spherical model clearly refuted the Epicurean criticisms of this aspect of Stoic philosophy (p. 107). If Hero's glass sphere was, in fact, used for this purpose, then there can be little doubt that it was used as a teaching aid for philosophy.

The devices discussed to this point were intended to illustrate some complex philosophy or philosophic principle, and were themselves mechanically elaborate. It is likely, therefore, that if they were used for instructional purposes, the individuals using them were adults. If, for example, one were to use Archimedes' mechanical planetaria, one would first have to know something about the concept of the cosmos at that time, or, at the very least, comprehend what the component parts of the apparatus were supposed to represent. If the user did not understand, then it is doubtful whether the user would learn anything useful from it related to cosmic theory. The same can be said about Thales' globe. The Antikythera mechanism, in addition, required the user to have some knowledge of geometry and mathematics, since the rotatable plates appear to be marked with degree gradations. A question that may be asked is whether there were any teaching aids and teaching machines intended for use with children and with individuals who did not possess a prior knowledge of a philosophy or a set of philosophical concepts? The answer is yes.

Roman Teaching Aids

Quintilian's pedagogical theory

Although most ancient elementary education appears to have consisted mainly of imitation, memorization, and rote exercises, there is evidence which indicates that various teaching aids were used in some quarters (Graves, 1918; Marrou, 1956). Marcus Fabius Quintilianus, known as Quintilian, was a Roman teacher and rhetorician of the first century A. D. His writings about his theories and practices of education have survived. Quintilian agreed with the idea that imitation was a very suitable means of education, but he also saw certain drawbacks in using it alone.

> And it is a universal rule of life that we should wish to copy what we approve in others. It is for this reason that boys copy the shapes of letters that they may learn to write. . . The first point, then, that we must realise is that imitation alone is not sufficient, if only for the reason that a sluggish nature is only too ready to rest content with the invention of others. For what would have happened in the days when models were not, if men had decided to do and think of nothing that they did not know already? The answer is obvious: nothing would ever have been discovered. (Quintilian, 10. 2. 2-5)

His condemnation of the predominant use of imitation extended to the beginnings of elementary education.

> At any rate I am not satisfied with the course (which I note is usually adopted) of teaching small children the names and order of the letters [of the alphabet] before their shapes. Such a practice makes them slow to recognise the letters, since they do not pay attention to their actual shape, preferring to be guided by what they have learned by rote. (Quintilian, 1. 1. 24-25)

Ivory letters

Quintilian advocated the use of objects which enabled the student to formulate concepts or to conceptualize what was being learned. "I quite approve on the other hand of a practice which has been devised to stimulate children to learn by giving them ivory letters to play with, as I do of anything else that may be discovered to delight the very young, the sight, handling and naming of which is a pleasure" (Quintilian, 1. 1. 26).

Writing practice board

In addition, Quintilian also encouraged the use of teaching aids that would tend to develop a child's physical control of a sequence of desired movements. It was common practice, during Quintilian's time, for students to write upon hard wax tablets using a blunt stylus. The stylus was usually formed from wood or metal and was held in one hand. By drawing the stylus across the wax, in a manner similar to the way in which we use a pen on paper, a line, letter, or shape could be engraved in the surface. It was not normal for students to write upon papyrus or parchment, because of their high cost. In addition, the wax tablets were usually designed to be scraped down several times, thus presenting both a fresh writing surface and prolonging the use of the tablet, a feature not duplicated easily with a sheet of paper. Quintilian, as well, noted that the use of parchment and a pen required repeated interruption of writing because the pen, usually a quill, had to be replenished with ink at frequent intervals. Such interruptions were considered by Quintilian to be detrimental to the student (Quintilian, 10. 3. 31-33). A great deal of skill was required in order to form letters legibly on the tablet, given the hard surface of the wax. It would appear, from Quintilian's account, that many students had initial difficulty in writing without having their hands guided by an experienced writer. Apart from the difficulty in writing on wax, the beginning student would not be familiar with the proper sequence of moving his or her hand, wrist, and arm in order to form each letter correctly. The student, in such a case, would be attempting to master two skills at once; forming the letters correctly, and writing on wax. Quintilian recognized this problem and devised a solution. He recommended that the teacher prepare a wooden practice board for each pupil. The board was to have each letter of the alphabet engraved on it. The pupil would then practice tracing each letter, using the stylus. The stylus would tend to follow the grooves in the wood, thus guiding the student's hand, wrist, and arm throughout the tracing of each letter. With additional practice, the student would become familiar with the motions necessary to form letters correctly, and would thereby develop appropriate muscular control.

> Thus mistakes such as occur with wax tablets will be rendered impossible; for the stylus will be confined between the edges of the letters and will be prevented from going astray. Further by increasing the frequency and speed with which they follow these fixed outlines we shall give steadiness to the fingers, and there will be no need to guide the child's hand with our own. (Quintilian, 1. 1. 27-28)

Although Quintilian's claim of eliminating mistakes on the wax tablets is likely an exaggeration, it is apparent that his method would provide some practice in the forming of letters, so that when a student attempted to write on the tablet, the primary difficulty experienced would be getting used to manipulating the stylus on the wax. Apart from providing the student with a means of individualized practice, this method also enabled one teacher to instruct several pupils simultaneously, without an undue concern that those not receiving assistance were not writing properly.

One may ask why Quintilian's practice board is considered to be a teaching aid rather than a teaching machine, since there is input by the user and there is instructional feedback. According to the definitions set forth at the outset, the practice board is not mechanical. The board is not capable of performing some form of transformation. The transformation is performed solely by the user. The board is not, therefore, a teaching machine. In addition, the practice board was intended to be used in conjunction with a teacher, as an adjunct to instruction in writing.

Quintilian's performance objectives

The above two teaching aids devised by Quintilian may appear, initially, to be concerned with a single learning outcome or performance objective, to write the alphabet, a psychomotor activity. Although Quintilian did not say so in scientific terms, his teaching aids deliberately addressed different learning outcomes. Modern psychologists and educational theorists such as Bloom and associates (1956) and Gagné (1984) have also divided **learning outcomes**, or **performance objectives**, into categories or domains. Although such taxonomies were unknown to Quintilian, his differentiation of use of various teaching aids reflected an empirical knowledge of distinct and separate performance objectives, each of which required a different approach.

The use of ivory letters as an aid for children to form concepts of the letters of the alphabet indicates a concern for cognitive development, while the use of the practice board indicates a performance objective concerned with motor or psychomotor development. Quintilian also advocated teaching aids for activities which we could now consider to be concerned with attitudinal or affective development. "There are moreover certain games which have an educational value for boys, as for instance when they compete in posing each other with all kinds of questions which they ask turn and turn about. Games too reveal character in the most natural way. . ." (Quintilian, 1. 3. 11-13).

Although Quintilian did not actively divide performance objectives into the domains or categories described by modern theorists, it is apparent that a similar empirical division had been utilized. This observation supports the belief that Quintilian's use of teaching aids arose from the analyses of pedagogical problems: there was an evident need for them. Recalling Schlebecker's four elements for technological invention one may argue that Quintilian had enough accumulated knowledge to create the teaching aids, that there was an evident need, and that they were, for the most part, economically feasible. An evident weakness within the fourth element, cultural and social acceptability, provides an explanation why such teaching aids were not widely used throughout the ancient world. A major thrust of Quintilian's work was the criticism of other pedagogical approaches (Quintilian, 1. pr. 23-26; 1. 3. 13-18). While he may have believed his methods and his use of teaching aids to be the best, it is more than likely that others did not.

Other Roman Devices

Finger reckoning

We have seen how teaching aids were employed by Quintilian to assist in the instruction of basic writing and letter recognition. There is some evidence available that indicates that devices of a similar nature were used in the instruction of mathematics and arithmetic. Techniques such as finger reckoning, which entails ascribing numeric values to each finger and combinations of fingers according to an accepted pattern, were known to have been used extensively in the ancient world (Menninger, 1974, Vol. II, pp. 11-15). Quintilian mentions finger reckoning as an analogy to oratory, "If a speaker, by any uncertain or awkward movement of the fingers differs from the accepted mode of calculation, he is thought poorly trained" (Quintilian, 1. 10. 35). While Quintilian's statement indicates clearly that finger reckoning was used as an aid for calculation, it is not clear whether such a method was used for instruction in arithmetic, such as in addition and subtraction. It seems reasonable that a teacher could hold up three fingers on one hand and then two fingers on the other in order to illustrate tangibly how the sum of five was obtained by addition. This technique could enable the student to form a concept of the principle of addition. This idea would be congruent with Quintilian's philosophy of pedagogy. In such a case, the fingers would be used as teaching aids. There is no evidence, however, that supports this idea unequivocally.

Gaming pieces

A few ivory gaming pieces have survived which may have been used as teaching aids. The pieces, dating from the first century A. D., are circular with a diameter of approximately 290 mm, and a thickness varying between 2 and 4 mm. One side is engraved with a depiction of a hand holding up one or more fingers, while the other side is engraved with the corresponding Roman numeral. Figure 3 (after Menninger, 1974, Vol. II, p. 14) is an example of one of the gaming pieces.

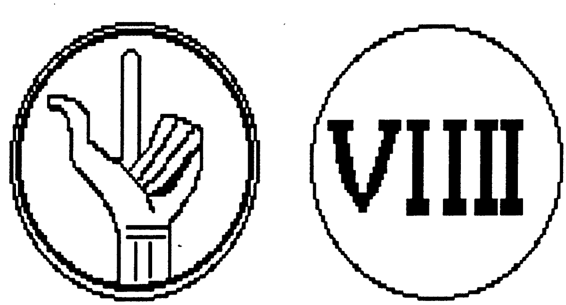

Figure 3.
Obverse and reverse views of a Roman ivory gaming piece

While it is likely that this type of gaming piece was used as a counter in a board game, it is also possible that it was used for quizzing purposes, in much the same manner that **flashcards** are used today. In either application, the gaming pieces would have served either to provide new information, or to have reinforced previously learned information. The gaming pieces would, therefore, be considered teaching aids.

The abacus

The abacus was also ubiquitous in the ancient world (Williams, 1985, pp. 56-69; Menninger, 1974, Vol. II, pp. 102-114). As with finger reckoning, there is some evidence that suggests that the abacus may have been used for instructional purposes (Pullan, 1968, pp. 94-101). The Roman poet Horace (65-8 B.C.) described boys travelling to school carrying their abaci, "hanging from their left arms the counters and the tablet" (*Satires*, 1. 6. 73-74). The earliest known ancient abaci consisted of some planar surface, usually a stone table top, onto which were inscribed lines. A line could represent units, or it could represent some form of multiple increment or fractions of unity. The significance of each line was sometimes indicated on the abacus as well. Small objects called counters (initially pebbles were used) were placed along the lines to represent numbers (Menninger, 1974, Vol. II, pp. 104-111). Surviving examples of ancient Greek abaci and depictions and writings of that period indicate that the table type of abacus was used primarily as an aid for calculation (Richardson, 1916, pp. 7-13; Williams, 1985, pp. 58-61). It is possible that these large early abaci were also used as teaching aids. By placing and manipulating counters on the abacus table, a teacher could show a student, or several students simultaneously, the concepts of addition and subtraction. Once the concepts had been learned, a student could then perform similar calculations on the abacus without help.

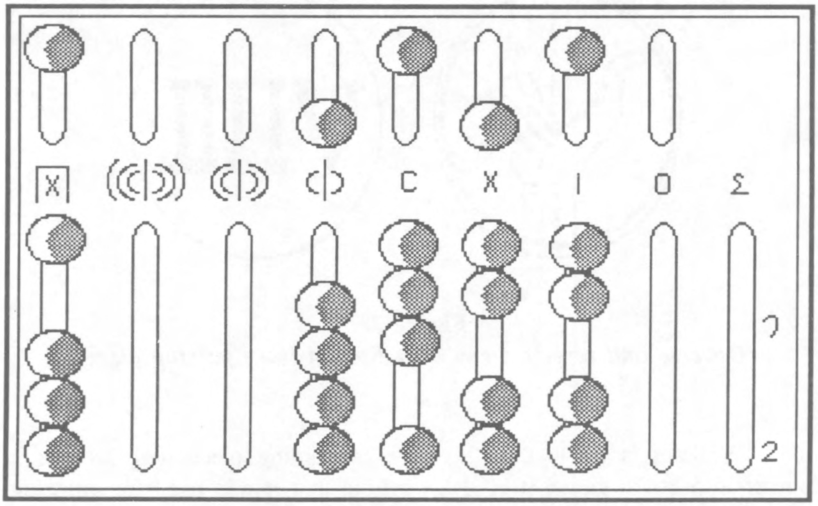

Figure 4.
Hand-held bronze Roman abacus

The Romans developed a hand-held version of this type of abacus. Surviving examples consist of bronze tablets, about the size of a postcard. The "lines" consist of slots into which are placed small grooved counters. Each slot is labeled as to its value (Menninger, 1974, Vol. II, pp. 111-114). This apparatus would be used in a similar manner to the larger version (Kretzschmer, 1978, pp. 3-5). Figure 4 (after Menninger, Vol. II, pp. 112-113) depicts a hand-held Roman abacus of the type just described. The abacus is displaying the number 1,005,372.

Neither type of abacus was mechanical; the counters were separate, manipulated by the user. This style of abacus, therefore, can be considered to be a teaching aid, in addition to its primary function as a calculator. It is important to note that the bead type of abacus, with which we are familiar, seems to have been developed during the mediæval period in the Middle East. From there its use spread as well to the Orient (Williams, 1985, p. 67).

Teaching Machines for Physical Training

So far, we have examined teaching machines and teaching aids that were used in conjunction both with the instruction of philosophy and with the instruction of academic subjects such as writing and mathematics. A significant area of instruction that has not yet been dealt with is physical training. In addition to the philosphical tenet of *Mens sana in corpore sano* [a healthy mind in a healthy body] (Juvenal, *Satires*, 10. 356), the ancient Greeks and Romans placed strong emphasis on such physical training as would result in the production of strong and superior soldiers. Physical training was also considered very important for such individuals as professional pugilists and gladiators, who comprised a significant segment of ancient entertainment.

The korykos

The training of pugilists in ancient Greece included extensive practice in correct punching techniques. In addition a successful pugilist was also required, simultaneously, to dodge punches from his opponent. While sparring matches could provide such practice, they entailed the use of two individuals and an appropriate location. Individual practice was realized by means of a special punching bag called a *korykos* (Aristotle, *Rhetorica*, 3. 11. 13). It was suspended from a ceiling or an arbour in such a way that upon being punched it would swing away from the pugilist in an arc. The *korykos* would then swing back towards the pugilist who was expected to avoid contact with it. Depending upon how it was suspended and the force of the pugilist's blows, the movement of the *korykos* could be quite rapid. Although it was not as elaborate a sparring partner as another pugilist, it functioned as an adequate teaching machine for both punching technique and dodging. The "input" to the *korykos* were the initial punches of the pugilist. The "transformation" was the motion of the *korykos* in an arc about the pugilist, and the "instructive feedback" was either the *korykos* hitting the pugilist, or the pugilist avoiding it. Avoidance of the blow indicated to the pugilist that what he was doing was appropriate.

The palus

Roman entertainment included displays by gladiators. Despite the portrayal provided in many contemporary screen plays, that gladiators were disgruntled slaves or wild barbarians, most of them were highly trained individuals who were expected to perform, in a skilled manner, a variety of hand-to-hand conflicts with different weapons. In addition, it was expected that most gladiators would survive at least a few engagements, since patrons usually paid, and paid considerable sums, for the training of individual gladiators. Most gladiators were taught in *ludi*, which were training schools that were owned usually by prominent individuals.

Training included complete control of the gladiators' environment and actions, with rewards given for appropriate behaviour, and punishment administered for undesirable behaviour (Quintilian, *Declamations*, 9.). The system resembled some behaviouristic approaches to pedagogy (Watson, 1930). Teaching aids were used in the training of certain gladiatorial skills, such as the correct handling of a sword. The proper use of a sword was necessary for two reasons. First, proper sword manipulation would result in a "hit" or an injury of the opponent. Second, proper sword techniques would limit the likelihood that the attacker would leave himself open to a retaliatory thrust or slash. Intense practice was seen as the primary method by which a gladiator would become proficient in the proper handling of his sword. Instead of having gladiators practicing against one another, where injury could occur, a *palus* or post was used by each individual. A *palus* was some form of wooden shaft or post stuck into the ground, so that it projected vertically about six feet (1,800 mm) (Vegetius, 1. 11). Using a practice sword and shield, the rookie gladiator was expected to attack that *palus* as if it were an opponent (Vegetius, 1. 11). The purpose of the exercise was to reinforce the instruction received on proper sword techniques. Although it is not stated in the sources, it is reasonable to assume that instructors supervised such training sessions and intervened if they observed improper technique. Initially, it seems that spears were used as *pali*, since an illustration on a lamp tondo depicts a gladiator training against a spear. Figure 5, (after a drawing in Daremberg-Saglio, p. 1582), shows a gladiator training against a spear *palus*. The use of a spear *palus* probably gave way to a more substantial post, since it was desired that the *pali* be rigid during training (Vegetius, 1. 11).

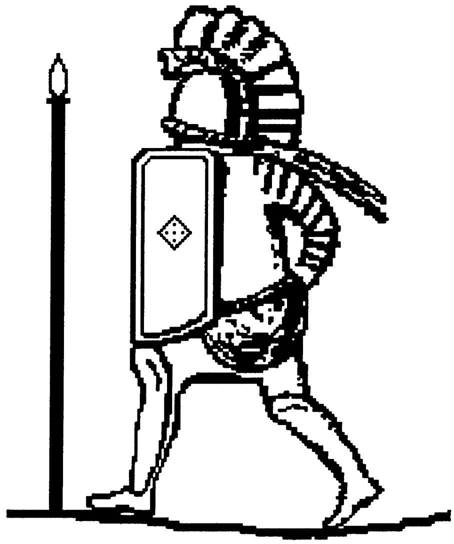

Figure 5.
A gladiator training at a palus

The rigours and the merits of gladiatorial training were recognized as belonging to a superior technique as early as 105 B. C., when the Consul Publius Rutilius introduced these methods into military training (Valerius Maximus, 2. 3. 2). While there were some within the army who did not approve of such radical changes, the success of Rutilius' legions convinced others. Frontinus (*Strategmata*, 4. 2. 2) notes, "Gaius Marius had the opportunity to select his army out of two already in existence, the army which had served under Rutilius and the one which had been under Metellus. . . He chose the army of Rutilius even though it was smaller, because he thought it to be better trained." The *palus* was one aspect of gladiatorial training that figured prominently (Vegetius, 1. 11).

One problem with the *palus* was that it could not indicate to the user whether the techniques used were appropriate or not. It is possible, therefore, that poor habits of an individual could be reinforced for considerable time before a supervisor appeared to correct them. What was required to overcome this problem was a device that would provide immediate feedback to an input – a teaching machine. Although accounts are vague from Roman times, it seems that such a device was invented during that period. It was called the *quintain* (Kuret, 1963, p. 192).

The quintain

Training at the *palus* usually occurred along the fifth street of a Roman military camp (Connolly, 1981, pp. 136-137, 218). The fifth street, called *Quintana,* gave its name to an improvement of the *palus* which transformed it from a teaching aid into a teaching machine. There is at least one modern author (Clare, 1983) who has stated that the *quintain* may have received its name in honour of a man named Quintus who was its supposed inventor (pp. 33, 170), but this seems to be no more than false etymology (Kuret, 1963).

There are several known varieties of *quintain*, but all operate according to one principle. A vertical shaft, usually of wood, supports a horizontal arm on top of the shaft. The arm is arranged so that it will pivot freely. One end of the horizontal arm holds some form of target. The other end supports a counterweight which could be in the form of a weapon or other pain-inflicting instrument (Kuret, 1963). The operation of the *quintain* was simple. Input was provided by the user who either aimed or struck at the target. Depending upon the intended purpose of the *quintain*, the target would either remain stationary or would swing away from the user. This transformation of the input would result in some form of feedback. If the intent was for the *quintain* to remain stationary, movement of the target would be an indication that the input was not correct. Conversely, if it was intended that the target be moved by the input, a stationary *quintain* would be an undeniable indication that the input was incorrect. If the blow was correct and the target swung away, the user would also have to dodge the counterweight or weapon. The concept of a device that would accept an input, perform a transformation and then provide some form of instructive feedback was not new to the Romans. It should be recalled that some Greek pugilists were trained by means of a *korykos*. It is logical to assume, therefore, that the Romans were able to meld the concept of the *korykos* with that of the *palus* in order to produce the *quintain*. Evidence to support this premise can be found in the writings of Flavius Vegetius Renatus, called Vegetius (fourth or fifth century A. D.). In his description of the training of recruits, he states,

> [T]hey used to learn to strike not with slashing but with thrusts. For the Romans not only easily beat those slashing but also laughed at them. For a slash, wherever one might make an attack, does not usually kill, since the vital areas are protected by weapons, armour and bones. On the other hand, a thrust made two inches deep is mortal; for whatever is thrust in inevitably goes into vital areas. (Vegetius, 1. 11. 12; translation, Buck)

Training solely on the *palus* would not be satisfactory for a recruit who was expected to learn to thrust rather than to slash. Without immediate feedback, it would be possible for a recruit to develop a habit of slashing before being corrected by a centurion or some other trainer. In addition, a solid wood *palus* is an inappropriate aid in training recruits to thrust two inches (50.8 mm). It seems much more likely that Vegetius was describing recruits training with *quintains*. This sentiment is also supported by Kuret (1963, p. 192). Given both Vegetius' description of military training and the criticisms of the suitability of the *palus*, the author has produced a drawing of a *quintain* that was likely used for training army recruits to thrust rather than to slash with their swords. The design is based upon the descriptions and the depictions of *pali* as well as mediæval *quintains*. The target, the large object on the right-hand side, was likely a burlap or a leather pouch filled with soft, light material, possibly straw. It is not known what the counterweight contained, but it is likely to have had a sufficient mass to balance the target. It is also likely that the mass of the conterweight was not too great, so that the *quintain* would rotate if it were struck with too great a force. Figure 6 depicts the author's concept of a Roman *quintain*.

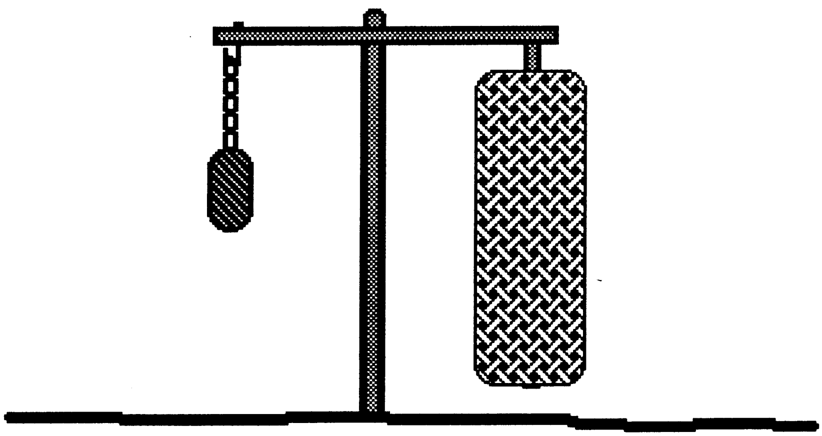

Figure 6.
Probable appearance of a Roman Quintain

Conclusions and Implications

This paper has described several teaching machines and teaching aids produced and used in the ancient world. They indicate that the concepts of individualized instruction and of employing technology in pedagogy are not new. It is important to note that there were two major areas where teaching machines were used: first, instruction in Stoic tenets (philosophical instruction); and, second, military training. While some facets of military training continue to employ devices similar in principle to the *quintain*, philosophy has shifted away from using instructional devices both to explain and to teach abstract concepts. The decline of Stoicism may have been the cause of this shift.

It is also important to note that some teaching aids similar to those devised by Quintilian and some teaching machines similar to Archimedes' spheres continue to be used. One may infer that continued use of such teaching machines and teaching aids indicates the soundness of pedagogical principles that are as much in use today as they were more than two millennia ago.

The purpose of the paper is not to advocate a return to earlier methods, but to provide information that may be applied in a useful manner to current and future developments in education, many of which parallel those of the ancient world. Above all, a knowledge of past successes and failures will assist in diminishing senseless "reinvention of the wheel". It is possible, for example, for one to encounter modern advocates of computer-assisted instruction who ponder the merits of the same pedagogical ideas as those expounded by Cicero more than two millennia ago, "Instead of describing a solar system or some theory about it, you might construct a computer simulation and allow people to discover their own theories by interacting with the simulation" (Levine & Rheingold, 1987, p. 233). A knowledge of the success of Archimedes' planetaria in enabling self-discovery of tenets of Stoic philosophy might have resulted in such a programme being available now, rather than just being considered. Although some benefit can be derived from knowledge of ancient teaching machines and teaching aids, such knowledge does not mean that all contemporary pedagogical developments and innovations are mere rehashing of ancient ideas and principles. If educators are to truly "advance" education, then they must be certain that what they are doing is new and is not a replication in ignorance of what was done in the past.

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