During his plenary address at this year's Botany Education Forum Bruce Alberts, President of the National Academy of Science, made a strong case for overcoming what we all know is the "bad news" in education – inertia. His address, and the Botany 2003 plenary talk by E. O. Wilson, are summarized in the News from the Society section of this issue. Both provided reason for optimism and suggested strategies for achieving our goals. Both presentations also served to preface some of the salient concepts presented in the Myths About Botany Education Research Symposium. Two of these concepts are addressed in the feature articles of this issue.

In the first article David Hershey tackles some misconceptions commonly perpetuated in the botany classroom. The constructivist theory of learning posits that students build upon what they know to create new understanding. A major problem arises when students try to build on incorrect ideas. Such misconceptions, or alternative conceptions, are extremely difficult to overcome because typically they seem so "common sense." Our job as teachers is to first make sure we understand the concept ourselves, then to make sure that we don't inadvertently reinforce students' misconceptions through careless word choice or oversimplification. Helmont's willow experiments are classic in the history of botany - - but perhaps not as novel as most of us think.

The second article addresses the importance of making botany interesting to students - - especially to middle-school students for it is during these critical years that the creativity and enthusiasm for science of most elementary students is somehow squelched. Sirce Kwai Giveon has no botanical training, but she saw plants as a way to enrich her art curriculum and in the process turned her students on to the wonder of flowering plants. It was a tremendous experience for her, her students, and for me as I fielded questions and shared in her students' discoveries. What a difference it would make to botany if each of the thousands of you who read this issue adopted a middle school class in your area. Imagine! Thousands of reinvigorated botanists! I bet Karl would have to deal with a boom of manuscripts in nine months - - and Wilson would have his boom of taxonomists in 19 years! Read, view, and enjoy! - - editor.

Misconceptions about Helmont's Willow Experiment

The 1648 potted willow experiment of Johannes Baptista van Helmont is widely discussed in biology teaching because it is the first known quantitative experiment in biology. Despite its familiarity, several misconceptions about Helmont's experiment have gotten into the teaching literature. The purpose of this article is to correct these misconceptions.

Helmont's Description

Helmont's willow experiment is often presented in its entirety because the description is so brief. Here is the first English translation from 1662 to refer to for the subsequent discussion,

"But I have learned by this handicraft-operation that all Vegetables do immediately, and materially proceed out of the Element of water onely. For I took an Earthen vessel, in which I put 200 pounds of Earth that had been dried in a Furnace, which I moystened with Rainwater, and I implanted therein the Trunk or Stem of a Willow Tree, weighing five pounds; and at length, five years being finished, the Tree sprung from thence, did weigh 169 pounds,

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and about three ounces: But I moystened the Earthen Vessel with Rain-water, or distilled water (alwayes when there was need) and it was large, and implanted into the Earth, and least the dust that flew about should be co-mingled with the Earth, I covered the lip or mouth of the Vessel with an Iron-Plate covered with Tin, and easily passable with many holes. I computed not the weight of the leaves that fell off in the four Autumnes. At length, I again dried the Earth of the Vessell, and there were found the same two hundred pounds, wanting about two ounces. Therefore 164 pounds of Wood, Barks, and Roots, arose out of water onely." (Helmont, 1662).

Helmont's Originality

Textbooks sometimes credit Helmont with the idea of the pot experiment to test if plants obtained their mass from the soil. For example, Moore and Clark (1995) noted that the "concept of plants as soil-eaters went unchallenged until 1648" when Helmont published his willow experiment. However, the consensus of historians is that Helmont's experiment was almost certainly inspired by Nicolaus of Cusa's 1450 book *De Staticus Experimentis*, which described a nearly identical thought experiment (Howe, 1965; Huff, 1966; Krikorian and Steward, 1968; Pagel, 1982). An English translation from *De Staticus Experimentis* reads,

"If a man should put an hundred weight of earth into a great earthen pot, and then should take some Herbs, and Seeds, and weigh them, and then plant or sow them in that pot, and then should let them grow there so long, untill hee had successively by little and little, gotten an hundred weight of them, hee would finde the earth but very little diminished, when he came to weigh it againe: by which he might gather, that all the aforesaid herbs, had their weight from the water." (Krikorian and Steward, 1968).

Nicolaus of Cusa was confident of the experimental results so he may have been relying on earlier sources, experimental data or common sense that gardeners did not have to routinely add soil to potted plants but they did have to water the pots frequently. Howe (1965) traced the quantitative pot experiment idea back to a Greek work of about 200 to 400 A.D. so Nicolaus of Cusa may not have been totally original either.

Helmont and his supporters, notably Robert Boyle, were part natural philosophers, part scientists, so they did not just rely on experimental data. They also used the theory of the ancient Greek philosopher Thales (62?-546 BCE) which stated that all matter arose from water (Krikorian and Steward, 1968; Walton, 1980). Boyle also cited the book of Genesis in the *Bible* as support for the theory (Walton, 1980).

Helmont and Water

Allchin (1993, 2000) stated that Helmont was "well aware that plants did not grow outside soil". However, herbals (Gerard, 1633) of Helmont's time described free-floating aquatic plants, such as "ducks meate" (*Lemna* spp.) or "frogge-bit" (*Hydrocharis morsus-ranae*)(Figure 1), that were common in Europe. Francis Bacon (1627) grew several species of terrestrial plants in water well before Helmont's experiment was published, including a rose he grew for three months. Bacon's conclusions were similar but not quite as strong as Helmont's, "It seemeth by these instances of water, that for nourishment the water is almost all in all, and the earth doth but keep the plant upright, and save it from overheat and over-cold." (Bacon, 1627). Other investigators used plant water culture in the mid-1600s including Robert Boyle, Thomas Browne and Robert Sharrock (Webster, 1966).

Figure 1*. Frog's bit, a free-floating aquatic plant (Gerard, 1633).*

Allchin (1993, 2000) stated that Helmont had no conception of distilled water. However, Helmont said he used distilled water in his experiment (Helmont, 1662), and distillation as a purification method was well known in Helmont's era (Multhauf, 1956). Alchemists, such as Helmont, often used redistilled rain water (Nash, 1957). Given Helmont's concern that dust might add to the dry weight of his soil, it seems clear that Helmont specifically used rain or distilled water because of their purity. Less pure water sources, such as well water or river water, would have contained more dissolved or suspended solids that would have added to the soil dry weight. In 1770, Antoine Lavoisier dismissed numerous water culture and Helmont-type experiments as inconclusive evidence that plants were formed exclusively from water because they had not used rain water or distilled water (Nash, 1957). However, Lavoisier could not criticize Helmont's experiment for that weakness.

Helmont and Gas

Allchin (1993, 2000) said "carbon dioxide [was] a substance wholly outside his [Helmont's] conception." However, Helmont coined the term gas, discovered carbon dioxide and is the "real founder of pneumatic chemistry" (Leicester and Klickstein, 1963). Helmont described several sources of gas sylvestre, his name for carbon dioxide, including belches, fermenting wine and burning charcoal, which is of plant origin (Leicester and Klickstein, 1963; Pagel, 1972). Helmont even wrote that when 62 pounds of oak charcoal were burned, they would yield 61 pounds of gas and 1 pound of ash (Leicester and Klickstein, 1963). Thus, Helmont knew that dry plant matter released large amounts of carbon dioxide upon burning. Helmont was apparently so dogmatic about the water-forms-all-matter theory that he ignored his data that plant dry matter was composed largely of carbon dioxide gas and his data that a small amount of soil was missing from his pot. Had he not been so dogmatic, Helmont might have used his data to conclude that fresh plant matter consisted largely of water but that dry plant matter consisted mainly of carbon dioxide gas and a small amount of soil minerals. That kind of conclusion would have advanced plant biology by well over a century.

Helmont's Pot

Allchin (1993, 2000) thought Helmont was "rather clever" and deserved "credit" for "isolating the relevant soil system within the boundaries of a pot." However, growing trees in pots was common in Helmont's time so Helmont was just using a standard technology.. The wealthy in Helmont's era often grew potted tropical plants, especially orange trees, and overwintered them in caves, stoves, greenhouses, or orangeries (Muijzenberg, 1980). Plants had been grown in pots as early as ancient Egyptian times (Baker, 1957). As mentioned earlier, historians have concluded that Helmont's experiment was almost certainly inspired by Nicolaus of Cusa's 1450 description of a nearly identical thought experiment that involved growing plants in a pot.

Allchin (1993, 2000) said that Helmont sunk his pot in the ground "as if the location was a significant parameter" to control. It is not known why Helmont sunk his pot in the ground so that is a guess. Hershey (1991) suggested some practical reasons such as greatly reducing the irrigation requirement by minimizing evaporation from the porous pot walls or preventing the planted pot from being blown over by the wind. The pot being blown over and spilling the soil could have ruined the experiment. Gerard (1633) illustrated a planted pot sunk in the ground (Figure 2) so it seems likely gardeners of Helmont's time knew of one or more of the practical advantages. Sinking the pot may have also prevented the roots from being killed by subfreezing temperatures (Hershey, 1991). Perhaps Helmont sunk the pot to prevent someone from falling in the hole left after the 200 pounds of soil were removed or because Mrs. Helmont didn't want a big, ugly pot sitting aboveground in the yard

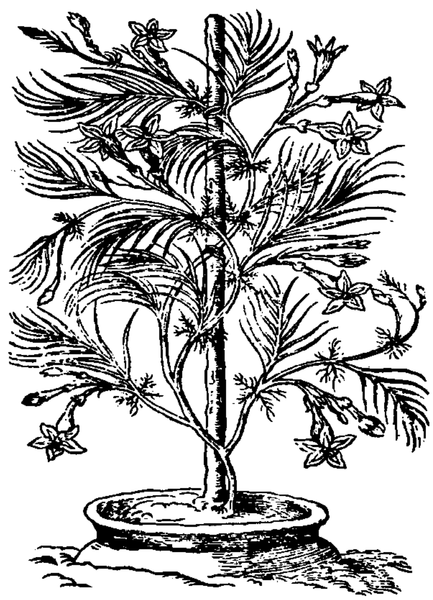

Figure 2. Cypress vine (Ipomoea quamoclit) growing in a pot sunk in the ground *(Gerard, 1633).*

for five years. Maybe Helmont did not even make the decision to sink the pot because it is quite likely that the wealthy Helmont had his gardener do some, if not all, of the experiment. Boyle had his gardener carry out his Helmont-type experiments (Krikorian and Steward, 1968).

Helmont's use of a metal pot lid to keep out dust is sometimes considered one of the more impressive parts of the experimental design (Krikorian and Steward, 1968). Helmont even coated the iron lid with tin to prevent rusting. However, common sense indicates that a metal lid with many holes would be ineffective in keeping out dust. Any dust that accumulated on the lid would have simply been washed into the pot when it rained. The lid would have been effective in keeping leaves, twigs, and other debris out of the pot. It might have also prevented larger animals from burrowing in the potted soil and prevented rain from splashing soil out of the pot. However, it would not have been effective in preventing surrounding soil from being splashed into the pot. Soil splashing into the pot was a disadvantage of sinking the pot in the ground.

Criticisms of Helmont's Methods

Allchin (1993, 2000) thought Hershey (1991) criticizing Helmont's experiment for not using replication lacked historical context. However, Boyle in the 1640s (Hoff, 1964) did three Helmont-type experiments before he had read Helmont's experiment (Krikorian and Steward, 1968). Boyle found 0 pounds soil missing, then repeated the experiment and found 1.5 pounds missing (Krikorian and Steward, 1968) which revealed substantial experimental error. Boyle lost the data of the third experiment (Krikorian and Steward, 1968). Woodward (1699) criticized the accuracy of Helmont's weighing and soil drying methods.

"I must confess I cannot see how this experiment can ever be made with the nicety and justness that is required, in order to build upon it so much as these gentlemen do. 'Tis hard to weigh Earth in that quantity, or plants of the size of those they mention, with any great exactness: or to bake the Earth with that accuracy, as to reduce it twice to the same dryness." (Woodward, 1699)

Helmont's Design and Analysis

Allchin (1993, 2000) stated that Helmont's experiment was "designed and interpreted appropriately" in the context of Helmont's time. However that is untrue.

- As mentioned above, common sense inidicates that the metal lid would have been ineffective in its stated purpose of keeping dust out of the pot, and sinking the pot in the ground would have created a problem of rain splashing soil into the pot.

- Helmont made no mention of the impossibility of completely separating soil and roots, which would have been a source of experimental error. Anyone who has tried to completely separate roots from soil knows that it is basically impossible.

- Helmont's description is contradictory because he says he grew the willow for five years but had only four autumn's worth of leaves. There would have been five autumns in five years. Helmont's said his 164 pounds of willow included just "wood, barks, and roots" (Helmont, 1662) so what happened to the leaves from the fifth season?

- Helmont made no mention of weighing inaccuracies even though accurate soil weighing was the heart of his experiment. Even Woodward (1699) noted that twice drying and weighing 200 pounds of soil could not have been done with any great accuracy.

- Helmont was inconsistent in his weighing technique because he determined soil dry weight but plant fresh weight (Krikorian and Steward, 1968). It was common knowledge in Helmont's time that plants did require water and contained large amounts of water because plant products were routinely dried before use, including firewood, grains, peas, beans, tobacco, cooking herbs, medicinal plants, hay, and some fruits, such as grapes to make raisins. Thus, the key question was what plant dry matter was composed of.

- Helmont's description of his experiment was very incomplete. He did not even mention the species of willow he used.

- Helmont is lauded for being quantitative but he ignored his missing two ounces of soil because he believed so strongly that all matter arose from water. Helmont was well aware that a small amount of ash or earth remained after burning plant material but did not consider the possibility that the ash represented soil minerals.

- Helmont did not have the data needed to conclude that 164 pounds of plant matter came from water alone because he had not measured the amount of water added to the pot during the experiment. The logical conclusion based on Helmont's published data would have been that very little of the plant fresh weight came from the soil.

- Helmont ignored common knowledge that manure greatly improved plant growth. Manure promotion of plant growth was well known long before Helmont's time (Tisdale and Nelson, 1975). Even Helmont supporter Boyle used that as a criticism in his 1666-67 work, *The Origin of Forms and Qualities*,

"And indeed experience shews us, that several plants, that thrive not well without rain water, are not yet nourish'd by it alone, since when corn in the field, and fruit-trees in orchards have consum'd the saline and sulphureous juices of the earth, they will not prosper there, how much rain soever falls upon the land, till the ground by dung or otherwise be supply'd again with such assimilable juices" (Hunter and Davis, 1999).

Helmont as Hero and Fool

Allchin (1993) stated that it was the "Most Outlandish Use of History in Biology Education" to portray Helmont as "both hero and fool." However, in his era Helmont was regarded exactly that way (Pagel, 1972) because his "combination of mysticism, magic, alchemy, and new science irritated even his contemporaries" (Heinecke, 1995). Even Helmont admirer, Boyle had that hero-fool view because Boyle thought a mysticism-heavy treatise written by Helmont was misattributed to Helmont by his detractors (Heinecke, 1995). Boyle couldn't comprehend how Helmont, who made many important scientific discoveries, could also produce such unscientific nonsense. Pagel (1972) noted that Helmont's writings are difficult for modern readers because his scientific work is mixed in with his nonscientific discourses on such things as religious metaphysics and cosmology. Helmont also believed in spontaneous generation, that the philosophers' stone could be used to turn other metals into gold and that applying salve to the weapon that caused a wound would promote healing of the wound (Pagel, 1982). A publication on the latter subject got Helmont arrested and convicted of heresy under the Spanish Inquisition (Pagel, 1972).

Woodward Disproves Helmont

Textbooks often follow up a description of Helmont's 1648 experiment with a discussion of Joseph Priestly's 1770s experiments (Kaufman *et al.*, 1989; Moore and Clark, 1995; Weier *et al.*, 1982). They rarely mention how John Woodward (1699) disproved Helmont's willow experiment. Woodward (1699) used water culture experiments in which plant growth was much greater in water containing a little soil than in plain water or distilled water (Table 1). Unlike Helmont, Woodward (1699) measured the water used by his plants and provided the first quantitative measurements of transpiration (Table 1). Woodward improved upon Helmont by using replication and growing his plants indoors under more controlled conditions. However, Woodward (1699) too failed to measure plant dry weight or make the connection that the dry matter absorbed from the water was insufficient to account for the entire gain in plant dry weight.

Table 1. *Effect of water source on spearmint (Mentha spicata) growth and transpiration in water culture (Woodward, 1699).**

Water source	% fresh wt. gain	Transpiration Ratio**
plain rep. 1	100	111
plain rep. 2	126	95
plus soil rep. 1	222	64
plus soil rep. 2	309	53
distilled	36	215

*Glass containers were covered by parchment to prevent evaporation. The stem was inserted through a hole in the parchment. Plants were grown for 56 days in a windowsill in June and July 1692.
**Grams of water lost divided by grams of fresh weight gained by plant.

Although Woodward (1699) showed that Helmont's conclusion was wrong, Woodward's work has been largely overlooked (Stanhill, 1986) while Helmont's willow experiment is still widely mentioned in biology textbooks and histories of science. The detailed case history by Nash (1957) does not even mention Woodward. Even in his own time, Woodward (1699) was overlooked. For example, Stephen Hales reported many transpiration measurements in his classic 1727 book, *Vegetable Staticks*, and made conclusions virtually identical to Woodward's but just briefly mentioned Woodward (Stanhill, 1986). In 1770, Lavoisier did not mention Woodward in his repudiation of Helmont's pot experiment and plant water cultures as proof that matter arose from water alone (Nash, 1957).

Woodward's (1699) convincing experimental data that Helmont's conclusion was wrong went largely unnoticed possibly at least partly because his reputation was later tarnished by severe professional disputes in his main fields of medicine and geology (Stanhill, 1986). These disputes resulted in a duel and his expulsion from the council of the Royal Society (Stanhill, 1986). Woodward's (1699) title was also vague. Had he used a title such as, "Experiments that Disprove Helmont's Willow Experiment," his work might have gotten more notice.

Lessons from Helmont's Experiment

The first sentence in Helmont's biography reads "Pessimism, scepticism and criticism are the outstanding key-notes of all of van Helmont's works and researches" (Pagel, 1982). However, he did not apply enough skepticism and criticism to his willow experiment. It was still a very useful and important experiment in the history of biology but was much less than it could have been. From a modern perspective, it does provide some valuable lessons for biology students.

- Do not ignore your own data when making conclusions. Helmont ignored his missing two ounces of soil and his other data that charcoal, derived from plants, produced mainly gas when burned. Had Helmont concluded that plant dry mass consisted of a small amount of minerals absorbed from the soil but mainly of gas sylvetre, his name for carbon dioxide, he could have advanced plant science by more than a century.

- Be objective and do not try to prove a particular hypothesis or theory as Helmont did. When you are not objective, you are likely to make wrong conclusions. Helmont's theory that water formed all matter made him conclude that all 164 pounds of willow came from water even though he had not measured how much water he had added to the pot. Helmont also ignored his missing two ounces of soil because his theory did not allow him to consider the possibility that the small amount of ash remaining after burning plant matter could have come from the soil.

- Consider common sense or preexisting knowledge even if you have no quantitative data to support it. In Helmont's case, he ignored common knowledge that manure promoted plant growth and that fresh plant matter did contain large amounts of water.

- Scientists sometimes overlook or do not acknowledge preexisting work as Helmont did for Nicolaus of Cusa's 1450 book describing a pot experiment like Helmont's and Bacon's 1627 work on growing plants in water. This was especially true centuries ago when scientific literature was not as widely available but can still occur. Allchin (1993, 2000) did not cite any historical literature on Helmont to support his claims and made errors.

- When publishing an experiment, describe the materials and methods in enough detail so others can repeat it. It appears no one ever attempted to repeat Helmont's five-year experiment with a willow tree. Helmont scholar Pagel (1982) even warned that trying to repeat Helmont's willow experiment as described "may run into technical difficulties" and "may lead to different results." Describing an experiment as basically unrepeatable is one of the worst criticisms that can be made.

- The first person who publishes an experiment gets the credit even if others proposed or did it earlier. If historians were convinced that Nicolaus of Cusa was actually describing a completed experiment in 1450, rather than just a proposed experiment, Nicolaus of Cusa would have gotten the credit instead of Helmont. Similarly, if Robert Boyle had published his Helmont-type experiment before 1648, he would have gotten the fame.

- An experiment may be considered valid long after other published results that disprove it. Woodward (1699) showed Helmont's conclusion from his willow experiment was incorrect but Woodard was largely overlooked in his era and ever since (Stanhill, 1986).

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Blooming Prints

I needed to get some flowers with some guts and muscles yet were beautiful and delicate. I didn't need these flowers to adorn my desk; I needed them for new information to give to students. I am an art teacher at Starlight Cove Elementary School in Lantana, Florida. These fifth grade boys and girls are budding into young men and women and I thought that delicately beautiful, gutsy muscled flowers would be something they could relate to. Our project, required by the Florida Sunshine State Curriculum, provides 5th Graders the experience of Relief Printmaking. Their suggested theme is Plants. Teachers are given leeway in how to focus their lessons.

In my experience of previous years, I have put up posters and silhouette shapes of flowers on the walls and passed around books about plants, and even brought flowers to school from my garden. However, I continued to get the question from the kids, "what do I draw"? That's mostly from the boys. The girls tend to make frilly daisy chains. Their prints came out well crafted but lacked some visual oomph. This year, I was determined to help them understand what they were looking at.

The best way I know how to get children to dig into more focused observation is through using Science