# Science Education for a Complex World

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**Abstract**

The New Sciences raised questions about traditional understandings of and approaches to the sciences and the cosmologies underlying them. As science discovers new ways of thinking about itself and the world it investigates, science education must create new ways of teaching science. Reynolds (2007) argued that Goethe's method of studying the natural world provides a way of approaching science that honors mutuality, context, and relationship and reunites a world that has become artificially fractured. We have created a model of science education that includes Goethe's approach to the study of nature. We report the results of a pilot study in an undergraduate science methods class as viewed by an educational psychologist, a science educator, and a botanist.

## A Goethean Approach to Science Education

"What sort of science is that which enriches the understanding but robs the imagination? .. if we knew all things thus mechanically merely, should we know anything really?" Zajonc (1998, p. 18)

Reynolds (2007) argued that Goethe's approach to the natural world, which he called "delicate empiricism" (Miller, 1995) may show us how spirit can be restored to learning by reuniting a world that has become artificially fractured. Lancelot Law Whyte (1896-1972) trained as a physicist in Britain, but is perhaps best known as a natural philosopher "in the grip of a grand, holistic view of nature." (Roszak, 1975) Whyte says that for Goethe, nature is the "sacred script, he merely records what he has seen or felt and in doing so may clarify for us what we have dimly sensed." (Whyte, 1949, p. 287) Goethe views the phenomenon as " a small world, existing for its own sake."(Holdrege, 1998, p. 215) and studies nature as an entity that has its own reason to be.

Goethe does study the details, but he does so in light of his awareness of the necessity of seeing the whole. Holdrege (1998, p. 215) illustrated this idea:

> Two animals may have the same surroundings, but they do not live in the same environment, which is, rather, the actual relationship between an organism and its surroundings…. the same watering hole is a very different environment for a lion (primarily a place where prey are stalked) than it is for the elephant (primarily a place to bathe). The environment as lived cannot be seen. It is a relationship and, therefore, cannot be described directly. In describing how the lion stalks, feeds, sleeps and so forth, we form a picture of the lion and its environment. The environment is revealed through the animal, and the animal is revealed in its relationship to the environment. This mutuality lies at the heart of contextual understanding." (1998, p. 217)

Similarly, Bateson says

> I think the first person who actually saw this clearly was Goethe, who noted that if you examine a cabbage and an oak tree, two rather different sorts of organism, but still both flowering plants, you would find that the way to talk about how they are put together is different from the way people naturally

> talk. You see, we talk as if the *creatura* were really *pleromatic*: we talk about 'things', notably leaves or stems, and we try to determine what is what. Now Goethe discovered that a 'leaf' is defined as that which grows on a stem and has a bud in its angle, what then comes out of that angle (out of that bud) is again a stem. The correct units of description are not leaf and stem but the relations between them. These correspondences allow you to look at another flowering plant—a potato, for instance—and recognize that the part you eat in fact corresponds to a stem. (Bateson & Bateson, 1988, p. 28)

## Goethe's "Delicate Empiricism"

Goethe's process of investigation passes through 3 stages: 1) empirical phenomenon which everyone finds in nature, which is then raised through experiments to the level of 2) the scientific phenomenon, by producing it under circumstances and conditions different from those first observed, and in a sequence that is more or less successful and a 3) final result that is the pure phenomenon which now stands before us as the result of all our observations and experiments. The pure phenomenon can never be isolated but appears in a continuous sequence of events. To depict it, the human mind gives definition to the empirical variable, excludes the accidental, sets aside the impure, untangles the complicated and even discovers the unknown.

## Implications for Science Education

We propose that Goethe's delicate empiricism contains the seeds of an approach to science education that can create a space for spirit. If children are brought closer to the natural world and to themselves, if they learn to rely upon and educate their perception and to think about phenomena as "little worlds unto themselves", perhaps they will not feel so alienated. If children learn to see the spirit of the oak tree in the oak tree and between the oak tree and the cabbage, perhaps they will be more likely to understand the spirit of the universe in its pattern, beauty and wonder in the living world and in themselves as a part of that world.

We understand that science classes cannot afford the time to allow students to generate their own knowledge exclusively and we are not arguing that they should. We argue that, in addition to their more traditional instruction, students should have an experience of investigation and observation in the Goethean tradition, including prolonged observation of the empirical phenomenon, scientific investigation, and experimentation.

***Empirical Phenomenon***

Goethe's approach is rooted in careful and prolonged observation of an empirical phenomenon. Students observe a phenomenon in the spirit of Goethe's delicate empiricism, which asks them to remain within the realm of phenomena and concentrate on form, color, pattern, and behavior. They are asked to stay open to the new and not get swept away by the already known, to attempt prolonged empathic looking and seeing grounded in direct experience. It is important that they observe the phenomenon in its natural context and over a long period of time. For example, in another project we asked first graders to observe plants, both an individual plant that they grow and a plant in the school yard, over the entire school year, making careful notes and observations. For Goethe, direct experiential contact became the basis for scientific generalization and understanding. How would the thing studied describe itself if it had the ability to speak? Our first graders have journals where they record their observations and answer that question each time they observe the phenomenon. Unfortunately, our undergraduates did not have an opportunity to observe an outdoor plant, so their observation experience was limited to the plants they grew indoors.

***Scientific Phenomenon***

Goethe did not view accurate description as a phenomenological end, but as a means by which the phenomenologist locates the phenomenon's deeper, more generalizable patterns, structures, and meanings. In Goethe's approach careful observation of an organism leads to a further search for what he called the "urphenomenon", an invariant principle amid a family of diverse phenomena—to apprehend the unifying movement among changing forms, the unity within diversity.

Goethe recognized the need to study phenomena under circumstances and conditions different from those first observed. The purpose of this aspect of Goethe's approach is to contrast and interrelate the observations as they appear in different organisms, bearing in mind that each organism we study is a totality of interwoven qualitative elements. We approached this through small group conversation between students who observed the same kind of plant and, at other times with students who observed a different kind of plant.

### *Experimentation*

Goethe understood the importance of experimentation, but argued that it should follow careful observation, not replace it. He further noted that it is not the single experiment that is decisive but the systematic multiplication of experiments—the establishment of an uninterrupted series of variations from which the underlying lawfulness is revealed of itself. He suggested that we order the experiments in such a way that, in progressing through the series of experiences, the underlying idea becomes immediately intuitive.

Our research team located some of the earliest written reports of experiments on plants. We are creating a children's version of these reports that will become a book to be read by, or to, the children. It is our intent that this book will allow children to have a virtual experience of the process of systematic experiments leading to some of the current knowledge about plants, including some of the conclusions shown to be false by later experiments. Thus, children may gain an idea of how scientific ideas are tested and clarified, and come to see that the best of science does not always lead to "truth" and that it is the series of experiments that are informative, not a single experiment. Unfortunately, we did not complete this task in time for the undergraduate pilot project.

## Method

Our team has begun 2 tests of these ideas, one with a science methods class composed of undergraduate students and one with a class of first graders. The challenges for the undergraduates will differ from those experienced by younger children, of course. They bring more preconceptions about science and more knowledge (not all of it accurate). They tend to be more distanced from processes of direct observation and description than their younger counterparts. They have the limitation of attending class 3 days a week, which creates gaps in the observation of their plants. This is particularly limiting for the students observing the fast grow plants.

The first graders are following a similar protocol, with the exception that they will observe their plants every day, and their "journals" will be somewhat more limited. These students will also have the opportunity to observe a plant for an extended period of time in its natural habitat outside the school building, thus opening up more possibilities of observation due to context (e.g. weather, soil, insects). They will also hear the stories written for them about early experiments with plants. Since we have not yet completed the project with the first graders, we report here only on the results of the pilot project with the undergraduate students.

### ***Participants***

This research was conducted within the School of Education at a private university in the West. The participants were students in a science methods course for students majoring in an early childhood education program. The students entered the College of Education in a cohort as juniors, having taken three science courses in the university core. The average GPA for students in that program is 3.27, and the average SAT score is 1121. The seventy-four students were divided into two sections with 36 in one section and 38 in the second section.

*Procedure*

On the first day of class, the students were introduced to the 'plant project' - a project that would begin that day and continue for about nine weeks. Students were encouraged to observe in the spirit of Goethe's delicate empiricism, which asks them to remain within the realm of phenomena and concentrate on form, color, pattern, and behavior. They are asked to stay open to the new and not get swept away by the already known, to attempt prolonged empathic looking and seeing grounded in direct experience.

The students worked in groups of four as they followed the directions for planting FastGrow seeds and setting up the lighting system, or decided how they would plant their eight lima bean seeds, or discussed what to do with a 'sprouting' potato in order to have a plant grow. When their seed/plant was established, they were told to observe, discuss, and record the growth and development twice a week during class time. In addition, all students observed cuttings from Wandering heart placed in water from the classroom sink.

Students used the first 20 minutes of each class for 9 weeks to examine their plant and make notes so that they could record their bi-weekly reflection. They were encouraged to discuss freely at their table as well as between tables. The instructors used questions to prompt ideas but did not directly answer student questions. The students were given a point for each entry regardless of the quality.

*Analysis*

Although we are in the preliminary stages of analysis, we have made some observations and have analyzed the journals of 4 randomly selected students from each of the 3 plant groups (lima bean, potato, and fast grow plant) for a total of 12 of the 74 journals. Three members of the team (the science education professor who taught the course, a professor of educational psychology, and a science professor from a nearby community college) read and coded the journals. Then each of us independently reviewed the report of these codes and memos and wrote our observations.

## Results

### *Science Education Professor*

*Lima Bean Group*. Each of the groups began their journal with a description of how the set up their lima beans; however, none of the groups were explicit enough for the reader to be able to set up a similar event. Two groups tried to establish an experimental design by doing different things to the two cups. Also, none of the groups give the day, date, and time of their observations.

Three major misconceptions (water, sunlight, soil) were evident in all four throughout the 8 weeks. The most obvious and most often repeated was that sunlight was needed in order for the seeds to germinate. This is evidenced in statements like the following: "Are they not getting enough light?", "Since our bean are growing slower than other we placed them under the grow lights", "I don't' think it is getting enough sunlight due to the location. I only noticed that one of the beans on the side of the cup is starting to grow." In the last case the student was referring to germination.

They also think that a small difference in the location of the plant will make a big difference in the growth: "Every other week we have been keeping our cups in the window sill so they receive direct sunlight but this week the cups were out of the window and not in direct light." However, they grew….

The second was water. When the students find their soil to be dry, they do not mention that evaporation might be a cause. They blame lack of germination/growth on the dry soil without making the connection that in nature there are periods of wet and dry : "We then saturated the soil fully with water", "our plants were fairly swimming in water" and "I think this is because the full cup had more soil, so it was able to retain moisture for a little longer, therefore, …[it] wasn't quite so dried out as the other cup." One journal began most weeks with a report of the lack of water in the soil but did not attribute it to evaporation or to the plant using it.

The third was soil. Only one journal mentions 'plant food' and 'nutrients' and that one does not associate nutrients with the concept of mining nutrients from the soil. No groups suggest that they might need to add fertilizer to the soil. One student put some seeds in the soil and some on top of the soil. They seemed to think that the soil hinders the germination.

Students did not seem to notice that the relationship between the thin stem being too weak to hold leaves and lack of nutrition. Some descriptions were so vague that it was impossible for us to tell what they meant. They used technical terminology incorrectly. They seemed unable to tell the difference in the stem and the root at the beginning of germination. For example, one student noticed that "the roots of the bean all emerge from the same place and beans turn green when they are growing".

*Potato Group.* The same trends were observed with this group as the Lima Bean group. Students' descriptions were inadequate, gross misconceptions were present, and often concerned water, sun and soil.

Students did not describe their original set up well enough for the reader to replicate it. None of the students indicated that they were beginning with a plant not a seed and none indicated what the old potato piece furnished for the sprout. The students did not seem to connect the sprouting with the growing of the Wandering Heart or with non-sexual reproduction. The descriptions do not indicate much depth in thinking on the part of the students.

Once again the student journals were riddled with misconceptions. Students misunderstood the purpose of roots: "will the it grow roots to hold itself down?" Evaporation was noted as the reason for the water loss.

*Fast Grow Plant Group.* At first I thought this might be the least productive because the life cycle goes so fast, but, based on the student journals, I now think it is the best. Even so, the water, sunlight, and soil themes were evident again, as were misconceptions, and misuse of technical language.

Even though the procedure used with these plants led to 'over-crowding', only one student noticed it. These students used fertilizer, but only one student noted that and thought that it might be an important factor. One student described the plant in terms of other plants: "looks like clover". Because these plants go through an entire life cycle in a brief time, they were the one group whose plants completed the life cycle, however the students did not realized that and wrote about their "dead plants" as if they should not have died.

One student asked at the end of week 8 "Would more water help them revive?"

As the instructor who wants the students to have some canonical knowledge of plant growth and about the process skills of science, I am very concerned about the lack of good observations and the observation/inference relationship.

***Educational Psychologist***

*Observation.* By far the most common journal entry was a simple observation of the most obvious dimensions of the plant: emerging structures such as stems, roots, leaves and pods and color and almost all of them were obtained visually. These low level observations were described in simple language such as "the one that was in the cup that was not totally covered had started to grow roots", "the other two seeds had grown roots and stems had started to spurt up." Other low level observations were reported as measurements, with no use made of the measurement to infer, question, or generalize. Measurements were simply reported as facts, e.g. "The roots are 1.5 cm long and the whole plant is 5 cm long. 6 roots are growing from the plant."

There were a few descriptions that included more detail. An example of this kind of description is: "The cup with the seeds above the soil looks very healthy and two huge new leaves have grown. In between the leaves there are three little leaves that are arrow shaped and the stem has grown a lot thicker. The other three seeds have not had much changes and only one of them has really even sprouted roots growing throughout the soil. They are mostly from the two healthy seeds but they weave throughout the whole cup."

*Relationships.* Very few students reported on relationships. Examples of observations of relationship include: "For all of the cups the stem size is in proportion to the size of the leaves, as in the bigger the leaf, the thicker the stem" and "It is pretty easy to tell which flowers are new and which are older because the older flowers lose petals quickly and the newer flowers hang on to their petals." Even when reporting such a pattern, the student did not check with other students to determine if this was an anomaly or a common pattern. The student also did not wonder or speculate why the plant might lose its petals with age.

Some students compared their observation of something in the plant to another phenomenon with which they have experience, e.g. "One bean has turned completely black and has an outer layer of thin waxy coating that resembles the same concept as a meal worm shedding their skin."

*Inferences.* Most disappointing was the number of students, by far the majority, whose only "inferences" were more the nature of assumptions made from a single observation: "For both of our plants we added more water because they were very dry from the grow lights", "One of the plants is starting to grow more to the right which is probably a result of the leaves becoming heavy." Most of the inferences were about the effects of water or sunlight and were made from single cases. No attempt was made to test the inference or to seek verification from the other students, other items in the room, or the readily available internet sources. One of my favorites was "one of the stems died off because it was not getting enough oxygen in the classroom." I assure you that none of us were having difficulty breathing. On a side note, when the students described a plant that they believed to be dead they often used words like "definitely dead" or "completely dead", the same words used to describe presumed dead plants by Joseph Priestley in 1779.

*Experiment.* A very few students made inferences based on experiment, "There is a big visible change between the two different modes of planting. On Monday I wondered if the beans that sprouted were facing the outside and were the ones that received the sunshine. When I checked them on Wednesday I noticed which direction they were facing before we took them out of the window sill and the ones that were facing the outside were in fact the ones that had sprouted the most dramatically." Another group tested the effects of sunlight, "We put the potato under the cabinet instead of in the window sill because maybe the potato doesn't need sun, or maybe the sun dried it out. "

Some of the "experiments" could perhaps more correctly be termed trial and error, since there was no attempt to control for the effects of more than one variable, "We decided to do different things in how we planted our lima beans to see if that would affect the way they grew. One cup was only filled halfway with soil (that cup has stars on the label), and the other cup was filled almost full with soil (that one has dots on the label). We put the beans right against the wall of the cup so that we could watch them grow. We also put pipe cleaners next to two of the beans (one in each cup) to see if that will affect the plant growth. The beans are at different depths in the soil to see if that will make a difference also. We then saturated the soil fully with water, put the cups in the windowsill, and now we just wait"

*Prediction*. There were a few statements that appeared to be or were stated as predictions, such as, "Next week I predict that the beans will have grown a lot because of the lamps". Sadly, few of these elementary predictions were followed by an observation to confirm or deny the prediction. The few that were reported were exciting, perhaps only because they were rare: "The new sprout contradicts my observations from last week because the tall stem with big leaves is thinner now and the stem without leaves is considerably thick."

Similarly, there were several instances where students posed questions, such as "I'm curious about how many roots are wrapped up in the paper towels. Since the leaves look different in the soil than in the paper towel, I wonder if the roots look different as well." Unfortunately there was little evidence of attempts to answer the questions. What appeared at first to be questions might more accurately be considered musings.

*Perry's "Position One" Thinking.* Many of these students seemed to be in what Perry called "Position One" thinking in his classic work on the intellectual development of college students. Perry described this position as "Basic Duality" and says that in this position a "division between the familiar world of Authority-right-we, as against the alien world of illegitimate-wrong-others." Perry states that "in this structure's most primitive form, Authority's omniscience is so taken-for-granted that no distinction is made between Authority and the Absolute. 'Truth' and 'what They say' function as tautological alternatives of expression, as do 'right' and 'what They want.'" There was blatant evidence of this in journal entries asking "Is this what you want?" and "Is this right?" There was a lack, in these journals, of recognition of the plant as its own authority, in the sense of the author of truth about what is happening to this plant. These students appeared to interpret the assignment as another situation calling for compliance and trying to get the right answers, with no sense that in this kind of setting that is, at best, irrelevant. They looked to the professor for the "right" answer and, when the professor did not provide it, they did not seek any other source.

*Botanist*

The Content Standards described by the National Science Education Standard for grades K-4 Life Science include Life Cycles of Organisms, Organisms and Environments, and Characteristics of Organisms (National Research Council, 1996). Most of the botany concepts in this study are included in these standards, which means that these students were expected to learn them (and almost certainly passed tests about them) in their k-12 education). However, this study surfaced a definite lack of basic understanding of botany concepts. Students incorrectly used basic botanical words such as bud, sprout and pod. One student misidentified the emerging cotyledon of a bean seedling as a bloom when the student wrote that their 2 centimeter long plant had not bloomed like the plants of other students in the class.

The comments pertaining to the elements necessary for plant life were limited, incomplete, and incorrect. Light was discussed as a necessity for the seeds to germinate and soil was referenced as being wet or dry but not as an integral part of the life cycle of plants. Nor did they give reference to the soil having a role in the growth or development of the plants.

Water was the sole, crucial factor that students consistently commented about with regard to the plants. Plants only needed water and sometimes air to thrive. The protocol for planting Fast Grow Plants included placing wicks in the containers during planting to maintain consistent soil moisture however; students watered the soil directly and misted the foliage throughout the project. Sprouting potatoes were placed in various amounts of water with reports of observing the levels of water but no acknowledgment of a possibility of ever having an excessive amount of water.

Standardization for comparisons between controls and variables was not evident. No report included a graph, chart or comparisons of changes over time. The student documents reflect science investigations as fragmented observations including measurement, reported as verbiage and validated by imagination.

Color was referenced in the reports. If the color was green, the plant was assumed to be healthy and yellow coloring was viewed as unhealthy. Potato sprouts were described as purple, but no inference as to why the purple pigment might be present. Roots were described as white but again, no suggestion of importance to the difference or significance of pigmentation.

Internet access was available to the students throughout the project. The students did not request literature relevant to plant growth nor did they access online resources. The students were confident in their reporting and questioned few of their findings.

## Discussion

Several things have become clear from their questions, journals and behavior in class during the project. First, these students were more engaged in this project than they were in previous classes. This was noted by the Molly Weinburgh, the professor who teaches the class and by another professor, Kathy Smith, whose class comes to the same room at the end of the Science Methods class. Kathy is not part of the project, but she commented on the fact that as the semester continued, she had to insist that the Science Methods students leave the room. This is new enough behavior that she reported it to us. Molly noted that the students observed their plant at the beginning of class, then took it to their table and kept it with them, and continued to observe it at the end of class (apparently until they were asked to vacate by the incoming class).

Engagement is not enough, however. It is clear that these students have very little knowledge of plants and what they do know is so decontextualized that it is not helpful in understanding a particular plant. For example, the students have all studied photosynthesis and can describe it, but they did not know why the potato plant that they placed in a dark closet had albino leaves and stem or why so little of the fleshy part of the original potato remained (compared to that of the potato plants that were kept in the sun). Unfortunately, this lack of knowledge is combined with false confidence in their incorrect knowledge.

The students do not understand the life cycle of plants and, even though they have studied seeds, they did not apply this knowledge when they noticed that the fast grow plants produced blossoms and subsequent seed pods. Students wondered if their plants would produce blossoms and seeds and did not infer the answer from their knowledge or from the fact that they had started their plant from a seed in the first place.

Perhaps most disturbing was the simplicity of student thought. There was nearly a complete lack of complex description, inference and observation of relationships. The only strategy these students seem to employ in seeking scientific knowledge is to defer to authority. The knowledge students did have, such as some botanic terms, appeared not accessible to them in a real life situation. They might be able to answer questions about the life cycle on a test, but when faced with a plant at the end of its life cycle, they do not expect it to die.

The etiology of these patterns is beyond the scope of this study, but we speculate that the emphasis on testing and the learning of "facts" in today's techno-rational educational world has contributed to it. It seems clear that we must design curriculum to better develop content, which was seen to be woefully inadequate in these students. It is equally clear that we must design science education classes for the development of student thought as well as for the content deemed essential for teaching science. While we still believe that Goethe's approach to science has merit for teaching science to children, we underestimated the effects of the undergraduate students' prior experiences and overestimated their ability to learn from observation. Since these students are a product of the traditional approach to science education, we are even more convinced of the need for an approach like the one we are studying.

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