Roth, W.-M. (2014). *Enracinement* or The earth, the originary ark, does not move—on the phenomenological (historical and ontogenetic) origin of common and scientific sense and the genetic method of teaching (for) understanding. *Cultural Studies of Science Education*. DOI: 10.1007/s11422-014-9606-z

Article

Enracinement or The earth, the originary ark, does not move—on the phenomenological (historical and ontogenetic) origin of common and scientific sense and the genetic method of teaching (for) understanding

Wolff-Michael Roth*

Abstract
For many students, the experience with science tends to be alienating and uprooting. In this study, I take up Simon Weil's concepts of *enracinement* (rooting) and *déracinement* (uprooting) to theorize the root of this alienation, the confrontation between children's familiarity with the world and unfamiliar/strange scientific conceptions. I build on the works of the phenomenological philosopher Edmund Husserl and the German physics educator Martin Wagenschein (who directly refers to Weil's concepts) to make a case for the rooting function of original/originary experiences and the *genetic* method to science teaching. The genetic approach allows students to retain their foundational familiarity with the world and their descriptions thereof all the while evolving other (more scientific) ways of explaining natural phenomena.

Key words Phenomenology · ontogenesis · history · culture · genetic method · teaching science · Wagenschein · Husserl · Weil

> *Perspicuum est igitur, terram in media mundi sede locatam esse oportere, &* immobilem [From this it is evident that the earth necessarily is located in the center of the world and *immobile*].
> (Aristotle 1560, p. 40r)

> – *Eppur si muove* [Still it (the earth) *moves* ([by] itself)].
> (Attributed to Galileo, June 22, 1633)

> *Die Erde* bewegt sich nicht [The earth *does not move*].
> (Husserl 1940, p. 313)

Eppur si muove [still it (the earth) moves ([by] itself)][1] Galileo is said to have stated under his breath—historians are certain that he never actually said it, though

* W.-M. Roth
University of Victoria, MacLaurin A567, Victoria, BC, V8P 5C2, Canada
E-mail: mroth@uvic.ca

[1] The Italian language (*si* muovere = *s*muovere), as the French (*se* mouvoir) and German (*sich* bewegen), uses a reflexive verb to express the fact that the agent simultaneously is the patient.

he might well have said it to himself—while leaving the room whereto the Holy Inquisition had summoned him. He had just recanted the claims made in his recently published book in favor of the Copernican view that the earth revolves around the sun and the sun rests rather than the opposite, which was the current dogma of the Roman Catholic Church. In the course of time, the Copernican description of an earth that moves around the sun asserted itself (rather than having been constructed), as scientists found themselves speaking in a new way after 100 years of conceptual muddle (Rorty 1989). Now the Copernican worldview is *the* view, that is, the scientific view and, like Galileo in the eyes of the Inquisition, anyone claiming today the opposite to the scientific view would be a heretic. Yet even adults continue talking about the sun as moving around the earth when asked for explanations of day and night (see below). Even more stunning, perhaps, the phenomenological philosopher E. Husserl and mathematician by training (i.e., Ph.D. in mathematics), in the third opening quotation, states the supposition that the earth really does not move. He does so in the context of an argument that no scientific conception would be possible unless there had been a stable ground on and against which we experience ourselves and other things move. This alternative approach to the earth as moving or resting can be taken from Husserl's inscription on the envelope in which he had gathered his manuscript: "Overthrow of the Copernican theory in the usual interpretation of a world view. The originary ark, earth, does not move. Foundational investigations of the phenomenological origin of the corporeality of the spatiality pertaining to nature in the first sense of the natural sciences" (Lawlor, in Merleau-Ponty 2002, p. xli). Even though our new understandings may overturn the fundamental sense of the earth as ground, this overturning is possible only because of an unmoving earth (Husserl 1940). In the shift to a Copernican worldview, this unmoving earth has not disappeared but has become sedimented into our common sense as the fundamental condition for conceiving of anything such as (relative) motion. Therefore, even though we eventually come to understand the earth as a thing moving among things, the unmoving earth *remains* the condition that makes any movement intelligible. (Much in the way that the virtual makes possible the real [Châtelet 1993] and that the invisible makes possible the visible [Marion 1996].) When this condition is not recognized, science becomes an alienating and uprooting experience (Weil 1990). The purpose of this paper is to articulate how everyday common sense constitutes the ground in which all of our scientific understanding is rooted, which Weil conceptualizes as *enracinement* (rooting). She opposes to this rooting the sense of uprooting and alienation (*déracinement*), which many persons have in their encounter with science. I describe a genetic approach to science education (Wagenschein 1988), which was designed to counter the alienation and *déracinement* that many students experience in science education.

From enracinement to the genetic approach in science education: an introduction

> Earth alienation became and has remained the hallmark of modern science. Under the sign of earth alienation, every science, not only physical and natural science, so radically changed its innermost content that one may doubt whether prior to the modern age anything like science existed at all. (Arendt 1958, p. 264)

Science, for non-specialists, often is strange, estranging (alienating), and deterritorializing because its concepts and theories are not grounded in and are even contrary to good common sense (Arendt 1958; Deleuze and Guattari 1972/1973; Weil 1990). Despite considerable amounts of funding that was poured into science education over the past 60 years, many students still are finding science hard and are dropping out rather than engaging in science, technology, engineering, and mathematics degrees (Seely 2012; Tabarrok 2012). Such students drop out because they are alienated by science. Already in the 1950s, the French philosopher and feminist Simone Weil (1990) explained the source of this alienation when ordinary people are confronted with science:

> What today is called instructing the masses is taking this modern culture, elaborated in a milieu so closed, so imperfect, so indifferent to truth, to lift everything that it still could contain of pure gold, an operation that one calls vulgarization, and shovel the residue as is into the memory of the unfortunate desiring to learn, as one gives a beakful to birds. (p. 62)

In this quotation, Weil critiques education for the way it takes up the results of modern scientific culture and its accomplishment (knowledge, theories). This uptake is described to occur by means of vulgarizing the cultural "nuggets," which are shoveled into the memories of unfortunate students. Weil suggests that modern science education uproots children because it confronts their everyday familiarity with the world with (scientific) concepts that are foreign and unintelligible—it is a process of *déracinement* (uprooting). This confrontation is a form of alienation (estrangement). Weil recommends instead forms of education that counter alienation by grounding themselves in children's familiarity with the world and in the expansion of this familiarity through immediate experience. Without symbolic interpretation rooted in the commonsense understanding of the world, there cannot be the experience of a unity of the everyday world and the sciences (Weill 1990).

Over the past decades, an increasing number of studies has shown that science education uproots, where familiar ways of being-in-the-world—e.g., feminine, aboriginal, First Nation, African American, and other everyday ways of knowing—are confronted with "Western" science without providing these students with relevant experiences that allow them to find a new home where they can set roots. This uprooting alienates students. That is, science education leads to a *déracinement* (deterritorialization) without providing opportunities that simultaneously lead to a new *enracinement* (re-territorialization) together with a sense of safety that comes with the feeling of being at home with something. As transnational migrants know from experience, feeling at home again in foreign lands takes time, frequently a lot of time. This is reflected in the genetic approach to teaching, which emphasizes the slowness of the process by means of which students expand what is familiar to them to eventually include the sciences and, thereby, regain the home that they have lost (Wagenschein 1977). However, much of the recent efforts still seem to go in the opposite direction, as exemplified in the Australian attempt to "accelerate science and literacy learning outcomes for Indigenous students" (Australian Academy of Science 2013). Rather than allowing indigenous students to evolve the familiarity necessary to grow roots and feel at home, this Australian curriculum endeavor attempts to *accelerate* learning. But there are no shortcuts to *enracinement*.

The German physics educator M. Wagenschein (1988), who argued for a different approach to science education when Weil wrote her book on *déracinement* and *enracinement* (i.e., 1950s), suggests that problems arise when science education teaches concepts too early, with too great of an insistence and addressing only the intellect. In this manner, students come to a rational "understanding," an expression by means of which he refers to students who repeat standard but strange phrases in formulaic ways and thereby loose their home and become estranged. Even today, estrangement and alienation characterize students' experience of science (Jung 2012). This can be seen from the fact that one quarter of the students graduating from the German elite schools—only about 10–15% of the total school population attended the Gymnasium in the days of his writing—believed the phases of the moon to be caused by the shadow of the earth (Wagenschein 1988). Similar results have been reported from interviews with Harvard graduates. However, all that suffices is to look at the relative position of the moon and sun in the morning (decreasing crescent) or evening (increasing crescent), when both are visible simultaneously, to understand that the earth *cannot be* between the two heavenly bodies. The damage to students caused is greater than the benefits that instruction actually accrues. Wagenschein emphasizes that science education not only pay lip-service to children's ideas but ground every new concept in *their* world, in *their* understanding, thereby allowing students to regain every little step of estrangement. The speed with which concept words are presented to students also is contrary to the recommendation to limit the frequency of ideas when the purpose is to get people to think rather than to besot them (Weil 1990). Learned concept words are mere instructions for a particular proven, confirmative intuition rather than as something that has arisen from truly intuitive understanding (Husserl 1940). Explicitly addressing Weil's concerns and taking a phenomenological perspective to the overturning of common sense in conceptual development—described by some scholars as "phenomenology and science education *integrated*" (Østergaard et al. 2008, p. 99)—Wagenschein (1977) presents a *genetic* approach to science education.

The genetic approach is distinct from a historical approach to science education, (Wagenschein 1977). Historical approaches often teach the concepts first and then let students affirm the scientific findings (e.g. Matthews 2000). In the genetic approach, on the other hand, teaching starts with the originary experience of children who explore a phenomenon, who find how to obtain and to lose it, and, in so doing, live through their first idealizations in a process that also has led historically to the initial scientific idealizations (Husserl 1976). In this way, children experience everything that is characteristic of science and that has led to its cultural history (Wagenschein 1977). The genetic approach emphasizes both phenomenological and evolutionary—as opposed to historical-teleological—aspects of science learning and becoming scientifically literate (Siemsen 2010). The economy of the genetic approach does not come from being "fast-lane, one-way street, temporarily used and destroyed afterwards" (p. 301) but rather from its emphasis of being rooted (*enraciné*) in familiarity with the world.

The genetic approach acknowledges that even the best teachers do not know what makes sense to each individual child and when and what it will learn. This is so because teachers cannot anticipate what a child/student will say in response to a teacher query. Therefore, teachers even are unable to anticipate their own contributions to classroom conversations only seconds hence (Roth 2013; Wagenschein 1977). The genetic approach evolved because it follows the *actual* development of children in contrast to current science education, which is thought from its "*end*, starting with the basic concepts and the mathematical structures . . . to be learned" (Østergaard et al., 2008, p. 110). The genetic approach recognizes that this traditional approach—including in the historical approach to teaching science—*cannot* work because students, by the very fact that they do not know the concepts, cannot actively orient toward learning them (e.g. Roth 2012b).

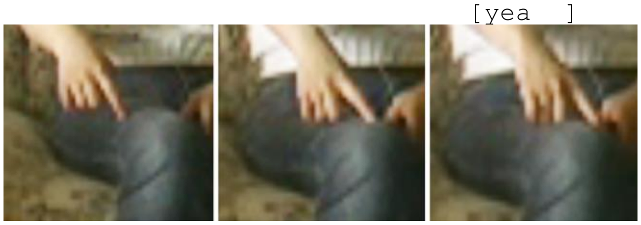
In this paper, grounding myself in Husserl, Wagenschein, and Weil, I offer the dialectic of *enracinement* | *déracinement* as a way of understanding what happens when we (are asked to) abandon our familiar world in favor of something that will be science. I articulate the ways in which our familiar world is the unmoving ground in which we have grown roots. I show why and in which way it makes sense to say that the earth does not move—here following the philosopher E. Husserl—and I articulate the implications—here following the German physics educator M. Wagenschein—for a *genetic* approach to science education not only with respect to the theories of the solar system but with respect to the relationship between every kind of experience and the scientific way of explaining them. That is, all the while drawing on the linguistic repertoire afforded by the astronomical discussion, this paper is not about astronomy and the question whether or not the earth moves but it is about the fundamental rooting that we have in the earliest forms of experiences in this world and language.

The earth does not move—literally

"*Perspicuum est igitur, terram in media mundi sede locatam esse oportere, &* immobilem [From this it is evident that the earth necessarily is located in the center of the world and *immobile*]," Aristotle wrote. Today, as many as 95% of the people and including most college students are said to talk about astronomical facts and events in ways that are not consistent with science (Reuell 2013). Some science educators propose a cultural-historical perspective, which emphasizes the ways in which we use vernacular to talk about frequently unknown situations in ways that make intuitive sense and that do not inherently lead to contradictory statements (Roth et al. 2008; Schoultz et al. 2001). We observe this to be the case in the following fragment, where a graduate student in science education (I) interviews Mary—a Taiwanese graduate student working on a PhD in language and literacy education—as part of a project about scientific and commonsense concepts in astronomy. Mary already has said repeatedly that she is being asked questions about phenomena that she has not thought about before. This particular fragment comes from that part of the interview in which the two talk about day and night. The fragment picks up with a turn sequence about the position of the sun in the sky, which is completed with the statement that the sun should be in the east in the morning. The statement is questioned: why? (turn 10). In the turn pairs that follow, the conversation establishes the sun as moving from east to west, which is elaborated into a movement from east to north to west (turn 17), followed by a movement to the south and east again (turn 19).

Fragment 1

07 M: so the sun is in the position of that a sky ((*hand gesture*))
position- ((*looks at interviewer*))
(0.18)
08 I: yea (0.86) a:nd which? direction. maybe east or north or?
09 M: uh:: ((*hand moves up to the chin, eyes move upward, pensive*)) in
the morning it should be in the east
10 I: yea. why.
11 M: why:: uh: i never think about that. () i thINK i:ts becau:se of
the movement of the sun,
12 I: [uh hm
[((*begins to nod*))]
13 M: the sun is moving]
14 I: so which? [direction the sun will moving?
[((*hand moves back and forth*))
from? () you know, where to] where?
as in pendulum motion))]
15 M: from east to west
16 I: uh hm
17 M: ea:st ta ((*gesture in the air, to upper legs to make "drawing"*))
(0:53) u:::m:: () east north [() in] the west an
18 I: [yea]



19 M: and the [south and [east again
[((*finger in the "south" position closer to Mary's body*))
[((*finger back in "east" position*)
20 ()
21 I: so you say [EAst and moving [to?
22 M: north

23 I: north () and then moving to

```
24 M:  east
25     ()
26 I:  east=
27 M:  =okay from () from east to north and to west
```

A common way of analyzing data in science education would attribute to Mary a misconception, an inappropriate mental model, or a visuospatial challenge in basic astronomy (e.g. Heywood et al. 2013; Vosniadou and Brewer 1994). In fact, conceptions and conceptual change research has shown that Mary draws on a way of talking about these phenomena common among Taiwanese elementary students (e.g. Liu 2005). Mary would be said to think—holding a conception that she has constructed in her mind during previous experiences—that the sun moves from east to north to west to south. In fact, she articulates the statement that explains night in terms of a sun that makes it day in the south. The second misconception that would be attributed to Mary is the fact that in the statements the sun is the entity that moves around the earth rather than the earth rotating around its axis. Such misconceptions are theorized as mental structures that are organized like concept maps on paper (Chi 1992). Those teachers working from that same research tradition to science education—i.e., conceptual change—intend to assist students in constructing a scientific conception, restructuring the concepts and models in their mind to produce new hierarchical relations between concepts that more closely correspond to the way in which scientists explain the phenomena (e.g. Vosniadou 2013). Although conceptual change may be "non-radical," in those cases that correspond to scientific revolutions—such as the changes students undergo from Aristotelian to Galilean conceptions of movement, from Aristotelian (Ptolemaic) to the Copernican worldview, or the change from ancient to modern understandings of the motions of the heart and the circulatory system—the changes are radical, that is, literally from the root up (Lat. *radic(x)-*, root). Thus, science educators working from the conceptual change perspective sometimes talk about eradicating children's and even college students' misconceptions (e.g., Fanetti 2001; Nam 2012), that is, literally uproot—eradicate, from Lat., *e(x)-*, out + *rādix,* root—the ways in which they (have come to) understand the world. If approached in this way, science education becomes an uprooting experience: students come to be *déraciné*, to use an adjective and noun that the English has borrowed from the French.

The eradication of ideas, however, appears to be a work of king Sisyphus, who, as Greek mythology goes, had to roll a boulder uphill only to see it roll down so that he had to do the work all over again. To understand this framing of the problematic, consider this. The interview was conducted around 2006, nearly five centuries after *De Revolutionibus Orbium Celestium* [On the Revolutions of the Celestial Spheres] (Copernicus 1543) was published, followed 90 years later by Galileo's publication of the *Dialogue* and his renunciation of the Copernican view before the Inquisition in 1633. It may therefore be surprising why, although the scientific revolution has changed the description of the relative movements of the sun and earth nearly half a millenium ago, (some) children and adults alike continue to explain the sequence of day and night in terms of a moving sun rather than a rotating earth. Why, at a cultural level, has the scientific conception not replaced the Aristotelian (Ptolemaic) conception long ago? Why is it still intelligible to talk about the sun as moving around the earth rather than having a consistent discourse that makes the earth rotating its axis, which makes the sun appear and disappear in the sky?

Of course, scientists themselves continue to marvel at a beautiful sunrise or sunset. A person surely would receive strange looks if s/he were to talk about the rotation of the earth while marveling at the sun "setting" behind clouds and mountains while traveling on the ferry from Vancouver to Vancouver Island (Fig. 1). That is, in our language—as in other languages, such as French, where the sun "goes to bed [se couche]" or German, where it "drowns [geht unter]"—it is the sun that moves relative to a fixed ground on which we stand and that always already reaches right up to our horizon. This aspect of our language, though more consistent with the Aristotelian (Ptolemaic) way of talking about the world than with the Copernican/Galilean way, is deeply rooted (*enraciné*) in our daily, intuitive, and commonsense experience of the world. Without requiring a geographical sense, the directions in which the sun is experienced—rising, noon, setting, midnight—"give beforehand the Whereto for every particular developmental formation [*Ausformung*] of regions that can be occupied by places" (Heidegger 1977, p. 103). That is, our sense of *place*, which has been used to theorize science education (van Eijck and Roth 2010), already is a consequence of a more fundamental being-in-the-world.

««««« Insert Fig. 1 about here »»»»»

Fig. 1. A beautiful sun*set* among the islands between Vancouver (Canada) and Vancouver Island.

Instead of pursuing the research of misconceptions, we may take a cultural approach to language. In such an approach, the exchange between the interviewer and Mary is understood in a tradition that considers words not to belong to individuals but always to speaker and recipient, author and reader (Vološinov 1930; Vygotskij 2005). That is, we analyze the exchange at the level of language, which never is our own but always already comes from the other. What we then hear are statements about the sun moving around the earth in a particular way (north is above, south below and on the opposite side of the earth) that are enabled by the very existence of language, its genres, and its intuitive ways of producing explanations. Thus, for example, the very fact that our language enables us to intelligibly talk about a beautiful sun*rise* or sun*set* allows a person unfamiliar with models of the solar system to infer that the sun is rising in the morning, moving across the sky in the course of the day, and setting again in the eventing (Roth 2008). However, from a pragmatic perspective, knowing a language and knowing one's ways around the world are indistinguishable (Rorty 1989). This makes it intelligible why our descriptions are so deeply rooted (*enracined*) in our experience of being- and becoming-in-the-world. To create a theoretical concept paralleling *déraciné* in the noun form, I borrow from the French and use *enraciné* (being rooted, having roots) and *enracinement* (rooting, the fact to be rooted). These words have a history in the philosophical discourse, pointing to the fact that we are deeply rooted in our everyday lives, language, intuitions, and experience. Any form of science education that attempts to replace this deep rooting will be counter-intuitive (e.g. Vosniadou 2013), challenges even adults (Hayward et al. 2013), and thus lead to a sense of *déracinement*, a noun I borrow from Weil's French, which goes with the already used *déraciné*.

In the fragment, Mary talks to the interviewer using words and statements that are deeply rooted in her experiences in/of the world, where the sun rises in the morning, moves across the sky, and sets in the evening. There is nothing in language that prohibits or makes unintelligible the intuitive world that she is articulating. In the very use of particular expressions to talk to the interviewer, we can see evidence that such talk is presupposed to be intelligible. In fact, for a researcher to state that Mary *has* a misconception, the statements that come from her mouth already have to be intelligible to the researcher as well. It is only then that the researcher can say that what Mary has said is incommensurable with what scientists tend to say about the earth and sun. Simply replacing this talk with other talk—or, in conceptual change language, to replace the misconception with a scientifically correct conception—may lead to an experience of *déracinement*. Today, much of science education, as science, is a fundamentally alienating experience (Jung 2012), because it robs children of their past experiences. We may return to the work entitled *Enracinement* (Weil 1990), where we can read about the effect of education in precisely this case of the sun and earth:

> One commonly believes that a little country boy today, student in primary school, knows more than Pythagoras, because he repeats in docile manner that the earth turns around the sun. But in fact, he does not look at the stars. This sun that one talks about in class has no relation for him with the one he sees. One tears him out of the universe that surrounds him, as one extracts the little Polynesians are torn out of their history by forcing them to repeat: "Our ancestors, the Gauls, had blond hair." (Weil 1990, p. 62)

Being able to talk about the universe in the way we have learned from Copernicus is insufficient. As Wagenstein (1977) notes in the case of the lunar eclipse, the acquired discourses intervene and eclipse the moon a second time so that it can no longer be experienced in the intuitive ways that a child may originally experience it. Children, as Weil notes, repeat the words in a docile manner without really understanding, comprehending from their roots up, what they are saying; and even adults are challenged when asked about the path of the sun across the sky and about models that explain the movement (Hayward et al. 2013). In this way, the children become déraciné, no longer able to hold on to their old beliefs and intuitions, and unable to hold onto the ones they are forced to acquire to maintain good standing at school. Thus, we may come to the conclusion that it

> is not sufficient to teach statements ("The earth moves about the sun"); it also is insufficient to illustrate them ("Like this apple around the lamp"). And yet we do not advance in most cases. We have to teach *understanding*. (Wagenschein 1988, p. 311, emphasis added)

What might it mean to teach (for) understanding? In the sense of Weil and Wagenschein, it means making provisions that children may use to connect their new science to the fundamental experiences of being- and becoming-in-the-world, our fundamentally intuitive ways of understanding, which arise even before we have words, since our births. Our familiar world in and with which we relate on a daily basis "has the character of nearness (Heidegger 1977, p. 102). It is in this world, with its experiences and intuitions, where everything "has its place" (p. 103), that our sense of *enracinement* is founded. It is in respect to the nearness of this world that we experience the distance of the foreign and strange. It is a world still mysterious and populated with phenomena that later disappear with and because of instruction. Thus, for example, Russian peasants without schooling categorized colors in very different ways than schooled individuals, relating the color names to their everyday experiences, such as "the color of mulberry leaves in the summer" (Luria 1979). But in some instances, and with some phenomena, those connections with original and originary experiences remain explicit. This allows us to understand the responses of Harvard graduates, who suggest that it is warmer in the summer because the sun is closer to the earth—where they talk from the grounded experience of feeling warmer when closer to a source of heat.

Why (in which sense) the earth does not move

In the preceding section, I articulate in which way our ways of speaking and our being- and becoming-in-the-world constitute an *enracinement* that provides us with a deep sense of familiarity. The familiar soil that we walk (upon) is the firm foundation of our sense of being *enraciné*. This understanding constitutes a fundamental ground on which all of our understanding is built. At the deepest level, as a precondition for the experience of motion and rest, there is an experience of a ground. Against and in reference to this ground, motion and rest come to stand out as figures (Husserl 1940). The ground, the earth on which we stand, itself retreats so that the figure can become salient. That is, from this perspective the earth (-ground) does not move. The philosopher distinguishes between two ways in which we may appropriate the reports, descriptions, and assertions (findings) of others:

> (1) illustrating the horizons of a ready "world concept," as it has been formed in apperceptive transmission and mental anticipation, drafts;
> (2) the way in the continuous constitution of the world concept from an already finished concept, e.g., Umwelt of the negro or the Greek in opposition to the Copernican, scientific world of modernity. (p. 308)

Husserl emphasizes the fact that the earth initially is not experienced as merely another body among bodies, such as the Copernican conception of the world requires. Instead, the world is experienced as the foundation of all experience that grounds everything we know; and the stars come to be seen as separate. It is only through subsequent experiences that the earth is constituted as an earth-body. The earth itself, in the original conceptual figure, neither moves nor rests. It is only in respect to the earth as ground that rest and movement become intelligible. To bring this statement into greater relief, consider this. Any letter or image presupposes a ground against which it can become figure. If there were to be no ground that withdraws so that the ink trace could stand out, no *thing* (i.e. nothing) would be seen. It is through and by means of the ground that the visible figure of the letter emerges from the invisible (Marion 1996). The same is the case for motion and rest, which can emerge only against a ground that in its very nature does not move. Returning to our case, therefore, once movement and rest are intelligible, the earth, too, may move or rest. That is, even in the constitution of the movement or non-movement of the earth, the movement transcending earth as ground is required. Rest and motion lose their absolute nature when the earth-ground become earth-body. Any dispute of this is possible only when the situation is considered from the modern perspective rather than from that of a world conceived in very different ways.

My own, originary flesh (immanent body) is experienced internally as a constituting body with which I move and feel, and as a body in motion, against a ground that is at rest. Here *flesh* is used to translate the German/ French terms *Leib/chair* used in phenomenology to distinguish our (immanent) living and (transcendent) sensing constitut*ing* bodies, endowed with the capacities of “I sense” and “I feel” from the constitut*ed*, felt material bodies outside, including one’s own body as material body (Merleau-Ponty 1964). Movement and my corporeal flesh as material body arise from the same experience, as *something* in *movement* with respect to a ground from which it is separate and on top of. Any confirmation, any demonstration, and any understanding ultimately is anchored and rooted “in my perceptual field and in the oriented presentation of the segment of the world about my flesh as the central body among others, all of which are given intuitively with their own essential contents at rest or in motion” (Husserl 1940, p. 311). My flesh in its relation to the surrounding world is the ultimate anchor ground, so that even sitting on a moving train or in a car, I consider these at rest unless I look outside of the window, at which time I perceive myself as moving with respect to the earth-ground. For the earth to be moving, I have to consider it no longer as the ground with respect to which everything else moves, but as a body among other bodies. I have to make a similar switch as that when I step onto the train. But the earth cannot be stepped on and off as in the example of the car or train, and, therefore, cannot be *experienced* in terms of rest and movement.

> As long as I do not have a representation of a new ground, as one such that the earth can have in its coherent and circular orbit the sense as a self-contained body in motion and at rest, and as long as I have not acquired a representation of an exchange of grounds such that both grounds become bodies, just so long is the earth itself really the ground, but not a body. *The earth does not move*—I may say perhaps it is at rest. (Husserl 1940, p. 313)

Here Husserl provides the fundamental argument why the earth does not move, and even when it eventually comes to move, this is only because a non-moving earth is the essential experience upon which the understanding of movement and rest come to emerge and to be constituted (passively). The understanding of space itself derives from early experiences of moving about, where the aboutness of the about is itself a product of the movement: movement is the generative source of space, bodies, and time (Roth and Lawless 2002; Sheets-Johnstone 2011). Even the birds who fly relative to the earth are no different than humans who walk, because their flying is part of a totality of kinaestheses that is related to an "I can" of the organism (Husserl 1940). Even if we could think of having two earths, stepping from one to the other so that we might think reaching relativity of the grounds, we could still conceive the one and the other as separate only when we already had constituted our bodies on the basis of the true ground.

We cannot therefore abstract individual development from the historicity of humankind and the common sense into which we are born and that surrounds us when we grow up (Husserl 1940). The earth can no more loose its sense as the primordial ground, a sense that constitutes the foundation of all sense we can make, than my flesh can lose its unique sense as the primordial flesh. Husserl points out that he is not contradicting Galileo's *Eppur si muove* by saying that it does not move. The earth does move, but it is the original and originary ark that makes possible the sense of movement in the first place and all rest as a modality of movement. This originary rest, however, is "not a modality of movement" (p. 324). It lies prior to any possibility of movement and rest.

The unmoving earth is the ground in which all experience is rooted; in fact, it is the ground against which any knowledge can take shape. As the above analogy with the letter standing against the white of the page makes evident, the ground is present and non-present simultaneously. Husserl's analyses show that the unmoving earth provides the ground that enables all of our knowing, because it is with respect to it that our kinaesthetic experience takes place and in reference to which our bodies are experienced as such. But this earth is not experienced as a collection of things that are or have been brought together. Thus, "the 'together' of the things that are experienced as one in the living present is not a simple 'being-experienced-together,' but the unity of a spatiotemporal or rather a together connected in spatiotemporality" (Husserl 1946, p. 335). The familiar world of the little country boy Weil (1990) writes about is of that kind: it provides the ground in which his intuitions and common sense take roots, the ground against which his experience takes place, where the experience is possible as such only because of the rooting ground, even if it is not itself perceived. In the perceptual field, "every newly entering object is already apperceived as object, as unity of appearances that are to be formed in this or that manner, brought to their unfolding" (Husserl 1946, p. 335). The totality of the unmoving and therefore rooting earth ground, in its presence as object totality "is a persisting total unity, which is not that of *one* object, but rather that of a configurative connection of all immanent, simultaneously experienced objects—it is the first world of experience" (p. 336–337).

Our lived-in world provides us with a unity of intuitive and self-evident facts that constitute the foundation of all evidence we can gather. The totality of fundamental evidence tends to be closed off as subsequent understandings are layered over and on top of it, sometimes undoing it all the while retaining it in its very foundation (Husserl 1976). This is the case in the cultural-historical evolution of the formal (discovery) sciences, including mathematics, especially when the discovery turns out to be a scientific revolution (Roth in press). Thus, for example, W. Harvey, an English Renaissance physician, overturned the then-common understandings of the function of the heart and provides an argument for the existence of the circular system of blood flow. As others, he had started out with the common conceptions then in place, fundamentally an Aristotelian view of the human body. However, the revolution emerging from his keen observations and descriptions did not get rid of his prior understandings. Instead, his new descriptions were enabled by his prior familiarity with the world, which provided a rooting ground, the objects, and the tools for arriving at a new understanding that overturned its antecedent (Roth and Friesen 2013a). The old understanding (i.e., the rooting ground) was both overturned and retained, as sediment, in the sense that they were essential for the new understanding to emerge. The interesting aspect of this is that in their science education experience, students today can re-experience this and similar transitions. They can follow the path of understanding (*Nachverstehen*) as they produce again (*Nacherzeugen*), in a dialectic movement of active and passive constitution, the historical processes that have led to new cultural knowledge (Roth and Friesen 2013b). In this way, "The ideal forms of theoria are without problems co-lived and taken on in understanding-again/after [*Nachverstehen*] and producing-again/after [*Nacherzeugen*]" (Husserl 1976, p. 333). And it is precisely this possibility to follow the path of understanding and to produce again the overturn and rebuilding of common sense that is emphasized in the genetic approach outlined below. That is, students today may re-live the genesis of knowledge and understanding in ways that both overturn and retain what they are bringing to their science lessons. The objectivity of the sciences—the fact that its experiments and empirical evidence can be produced at any time by anyone and anywhere—arises from these phenomena of re-understanding and re-producing the cultural-historical genesis of knowledge.

Crucial in this process of cultural-historical genesis of knowledge is that any subsequent knowledge—e.g., atomic physics as it exists today—cannot be the learning intention from the beginning. The evolution of the sciences is non-teleological; and it is this aspect that a truly *genetic*—in contrast to historical—approach to science education retains (Wagenschein 1977). Every science emerges from a fundamental and intuitive common sense of how the world works, established during first creative activities, which lead to further activities in a forever continuing appropriation. Every prior understanding is retained in the constitution of the new understanding so that "in every present the totality of appropriations constitutes the totality of premises for appropriation of the new step" (Husserl 1976, p. 367). Tracing the conceptual evolution backwards, there have had to be more "primitive" conceptual antecedents enabling a first scientific constitution based on what inherently was (self-) evident without that this self-evidence could be questioned any further. In this original step, the new could not have been anticipated because it was transcending, going beyond, and, therefore, was initially only darkly awakened (Roth in press). These are *insights* in the precise sense of the word, occurring suddenly precisely because they could not have been anticipated because incommensurable with what has existed before.

> It is easy to remark that even in human, and initially in every individual life, from childhood to maturity, the originally intuitive life, which creates its originally self-evident forms through activities on the basis of sense-

> experience, very quickly and to an increasing degree, falls victim to the *seduction of language*. (Husserl 1976, p. 372)

Important to science education, Husserl's work implies that it is not necessary to reconstitute the whole of the sciences, to traverse the entire chain of conceptual foundations from the original and originary constitutions to the present day. In each conceptual overturn, the nature of science is reexperienced (Roth and Friesen 2013a). A few exemplary experiences suffice for the individual to re-live and re-constitute the nature of the process of sciences, from its foundations in the originary forms of self-evidently givens to the present day (Patronis and Spanos 2013). On the other hand, if students' re-living the overturning and constitution of sense were impossible, "the sciences would constitute a tradition empty of sense" (Husserl 1976, p. 376). Husserl adds that this was, in his day, unfortunately the situation in which the European sciences found themselves.

From the aforesaid there are consequences both for philosophy of science and for science education. Thus "a phenomenological philosophy has to be genetic if it wants to respect the temporality of the originary lived experience [*vécu originaire*]" (Derrida 1990, p. 14). A genetic conception of teaching cannot be causal, aiming at the scientific conception as its telos. The experiential grounding [*enracinement*] and the novelty of knowing are irreducible to each other. That is, the everyday (common) sense is the ground, the tool, and the object of a transformation into new forms of knowing that in a way transcend and even reject the earlier forms. Any genesis of scientific understanding, therefore, involves the dialectic of *déracinement* | *enracinement*, for it uproots an original/originary common sense while rooting a new common sense. Yet the two forms of sense are irreducible: new knowledge cannot be explained on the basis of prior knowing; and yet the former is possible only because of the latter. The approach has immediate and tremendous consequences for science education. In the following section, I provide an argument for a genetic approach to science education, which has the purpose of rooting—in the sense of *enracinement*—any new understanding in the lived experiences of the students.

Implications—a genetic approach in/to science education fosters *enracinement*

> The setting of roots [*enracinement*] is perhaps the most important and most misunderstood need of the human soul. (Weil 1990, p. 61)

In English, there is a rarely used word for having taken roots, being rooted: enracined. It has its origin in the French verb *enraciner*, to which corresponds the noun *enracinement*. Thus is the title of an essay written by the French philosopher S. Weil (1990), which, because of the lack of an equivalent word, was translated as "The Need for Roots." *Enracinement* is an important aspect of knowing, whereby individuals remain grounded in and connected to the familiar worlds that surround them. The opposite, uprooting (*déracinement*), occurs in cases of brutal suppression of all local traditions, including the "brutal" suppression of the forms of knowing available to people. It is associated with the forms of knowing imposed and assessed by others until the moment that another form is imposed for a time period unknown to the person—which is what students experience when a form of knowing correct today (a particular atomic model, a particular way of factoring polynomials, Pluto as a planet) is considered false tomorrow (e.g., Pluto is not a planet but a plutoid). In science education, especially when it is practiced superficially, the empty assurance that what we see is only appearance leads to *déracinement* and a sense of a loss of safety and feeling-at-home in/with nature (Jung 2012; Wagenschein 1977). In fact, the various scientific revolutions have led to a general *déracinement* and loss of the security of home, but they also have come with a gain because the sciences have led to greater control over our condition (e.g., in the case of diseases and illness).

Science education, perhaps more than any other discipline-specific school subject, has been concerned with changing the ways in which children and student understand the world. In the conceptual change approach that dominates science education today, teachers (sometimes) are encouraged to e*radica*te the misconceptions students (are said) to have or encourage in them in *radical* conceptual change, and students are to be encouraged to abandon their misconceptions in favor of other, more scientific understandings. Not surprisingly, students experience science education to be "deeply uprooting," especially because "they feel coerced to accept the dominance of Euro-centric science" (Brandt 2008, p. 728). Even cultural approaches are cognizant of the fact that students' discourses that they bring from home and that characterize a particular form of being-in-the-world, conflict with the discourses that they are to acquire at school. Some therefore speak of boundary crossing experiences and the building of bridges (Aikenhead and Ogawa 2007), whereas others see students constitute a third form of culture, being-in-a-third-space, where they the cultures of the home and that of science are confronted "to form an intersection called the third space (synthesised science)" (Mpofu et al. 2013). But thinking science education in terms of bridges, which comes with associations of gulfs and abysses separating two *radic*ally—i.e., literally, from their root up—separate realms (Roth 2008), is not the same as thinking it in terms of *enracinement*, where new forms of knowing literally are allowed to emerge from their roots. Gardeners know of this when they graft a branch from a more fragile fruit tree onto a root that makes it more resistant or controls its growth. The enracinement and grafting metaphors allow new forms (scientific knowledge) to grow on old roots (familiarity with the world) rather than tearing the latter out. In gardening, the roots stock is chosen because it is well adapted to the local growing conditions, whereas the graft is selected for its fruit (flowers). Too often, however, students are torn from their familiar soils and worlds, making them repeat statements that appear to reflect understanding the world in new, more scientific ways. The loss that children experience is profound, and perhaps comparable to the loss of the world and the diaspora, the sense of dispersion and errantry that indigenous children experience when confronted with Western science (Roth 2008). They are like strangers/foreigners in their own language (Deleuze and Guattari 1980), who, "if they experience themselves as bastards" do so "due not to a mixing or intermingling of languages but rater to a subtraction and variation of their own language achieved by stretching tensors through it" (p. 133).

The point is not to eradicate [Ger. *ausmerzen*] children's original, intuitive relation to the earth and the heavens but, while keeping it in transformed and transforming ways, to associate to it the new relations that correspond more closely to science (Wagenschein 1988). The physics educator encourages us to allow children and students to learn that the new perspective on the earth and heavens, as significant and fascinating it may be, also constitutes a narrowing of the perspective that comes from the objectifying rationalist and rationalizing gaze. This narrowing comes with a loss of reality experience—such as when our marveling comments about the beauty of a sun*rise* or sun*set* are countered by a comment about the falsity of this conception and the mere rotation of the earth. Thus, for example, the teaching of astronomy does not have to undo and overcome the original and originary, non-distancing but identifying perception of and intuition about the earth—which is home, ark, and ground of everything we know. It does not have to rob us of our world that speaks to us in its concrete reality. In a similar way, students studying a stream do not all have to conduct investigations that correlate two or more variables but may, while their classmates are doing so, investigate nature through photography, recorded narration, and interviews with elders (Roth and Lee 2004).

School (book) knowledge constitutes a corruption in the face of such simple phenomena as the eclipse of the moon, frequently demonstrated by means of shadow play, which high school graduates may explain by means of book learning but which they seldom have experienced themselves (Wagenschein 1988). This is so because the bookish knowledge students acquire intervenes between the phenomenon and the person and, thereby, actually eclipses the moon for a second time so that the individual never comes to really see the moon as it presents itself to the naked eye. Because eclipses of the moon are infrequent, Wagenschein recommends silent documentaries of the phenomenon to be played repeatedly and investigated as if the children were actually observing the moon. In an era when most students have access to computers, they could replay such video sequences over and over again in the attempt to make observations that they subsequently describe in their own language and in terms of their familiar world.

The genetic approach allows students, by means of a small number of concrete examples, to re-live the original experiences that have led to a more or less radical change in the sciences. They re-live these not from the perspective of the concepts that the teacher might give them, as in the historical approach, but by extensively exploring the phenomenon to the point that their original explanations no longer suffice. Each child, at its own time, will engage the dialectic of *déracinement* | *enracinement* that also characterized the original idealizations. This is why a singular case, in which students delve in considerable depth, becomes a mirror of the whole of science, the whole world in a single raindrop (Wagenschein 1977). Using an example from mathematics, the author suggests that a lot if not everything characteristic of mathematics could be taught by and understood through considering the ancient proof of the fact that the series of primes is infinite. Such a consideration would lead to a more profound understanding of mathematics than the one that most college entering students ever develop. The single consideration of what happens to a rock dropped from the top of a tower can bring to light the physicists' ways of thinking and experimenting generally; a similar case can be made if students were to truly engage—not just for verification processes—to seek an answer to Galileo's question what happens when a ball is rolled down an incline. In this particular case, we know from the literature that (a) if students really were to try investigating the phenomenon, they likely would learn to become very familiar with how the phenomenon can be lost in more ways than in the way it is actually seen (Garfinkel, 2002) and (b) if the teaching is too superficial, even college students in science methods courses tend to lose their ground, become uprooted, and "get lost" (Roth et al. 1997). Relative to science education, Wagenschein (1977) also refers to a number of efforts that show how in studying a single nematode one could explain the essentials of biology; and using five to ten key animals suffices to exemplify all essential phenomena, concepts, and laws in the area of zoology.

Re-living some of the fundamental transformations in human understanding could and does lead to *déracinement*: if it is done hastily. Because the experience that comes with moving through a conceptual revolution is uprooting, science education simultaneously has to offer ways of finding a new ground at the same time. In this way, while losing ground in *déracinement*, students simultaneously set their roots in new ground that allows them to retain their *enracinement*. That is, students have to engage with a field of inquiry to such an extent that they develop a sense of being at home, at which time the phenomenon or concept to be learned reveals itself (Wagenschein 1977). All the while students are active, what they learn comes in and as a revelation. Fundamental—and foundation building—are those experiences that "shake the common base of man and thing (with which he grapples)" (p. 22). Elementary insights come almost on their own, accompanying the activity, in a form that has been called *collateral learning* (Dewey 2008). Thus, "[c]ollateral learning in the way of formation of enduring attitudes, of likes and dislikes, may be and often is much more important than the spelling lesson or lesson in geography or history that is learned" (p. 22). Both Dewey and Wagenschein emphasize that truly fundamental and formative experiences are *moving*, in intellectual and affective senses of the word.

Central to the foregoing description is the notion of experience as something that happens to us and that we suffer, something that we do not control and that affects us cognitively and emotionally (Ger. *Erfahrung*). I understand experience in the etymological sense of the Proto-Indo-European root *per-* articulated above, especially as denoted by the verbs to try, dare, and risk, put oneself in danger, carry over bring, fare, and to lead towards (Roth and Jornet 2013). Experiencing and experimenting, though they lead to new understandings, also come with perils, for example, with the danger of losing ground. A fundamental principle of the genetic approach is the concept of *enracinement,* rooting or grounding (Ger. *Einwurzelung*), which Wagenstein has borrowed from Weil. This concept points us to the effort to *ground* science education in the current knowing of children and students rather than in the effort of making them abandon the rootedness in their familiar worlds (van Eijck and Roth 2009). Genetic teaching does not seek a splitting of individuals, asked to adopt a new world while abandoning its simultaneously denigrated origins.

(This had been the now infamous cases of Canadian residential schools or Australian Aboriginals placed in institutions or adopted by non-aboriginal parents [*Stolen Generation*], where they were forbidden to speak their mother's tongue and speak in the English of their oppressors.) A genetic approach heeds the description of scientific revolution that emphasizes the non-teleological direction of evolution of the sciences and scientific knowledge: scientists did not

> decide on the basis of some telescopic observations, or on the basis of anything else, that the earth was not the center of the universe, that macroscopic behavior could be explained on the basis of microstructural motion, and that prediction and control should be the principle aim of scientific theorizing. Rather, after a hundred years of inconclusive muddle, the Europeans found themselves speaking in a way which took these interlocked theses for granted. Cultural change of this magnitude does not result from applying criteria . . . any more than individuals become theists or atheists. (Rorty 1989, p. 6)

Following the principles of the genetic approach means that children and students are re-experiencing this sense of the open and undetermined future of knowledge that emerges from their efforts rather than searching for something predetermined already known to others. There is a passive genesis of new knowing, which, precisely because unknown only moments before its emergence, cannot be anticipated: what is emerging as the new way of knowing is unseen and therefore unforeseen (Roth 2012a). The living and lived present is constitutive only "because emerging in its radical novelty of a past immediately constituted, it grounds itself in it and does not appear to itself in the present than over the ground of a passive continuity with the instant before" (Derrida 1990, p. 111–112). It is precisely this *passive genesis* that grounds [*enraciner*] individuals in their history. It is precisely the teleological aspect of science education, where students merely come to reify pre-existing and pre-determined forms of abstract knowledge, that also leads to their uprooting [*déracinement*] (Wagenschein 1988); it is instruction as conceived today that is responsible for students' experience of *déracinement* today (Weil 1990). Although well conceived, however, students may not immediately appreciate such a different approach to science education. As one study showed, students may perfectly well subscribe to a constructivist epistemology all the while rejecting extended open inquiry because they do not see how it prepares them for high-stakes (entrance) examinations (Lucas and Roth 1996).

On getting the earth to move . . . in science classes

> Translating an idea into its general genetic process is equally difficult as finding it in the first place. (Siemsen 2010, p. 310)

> Physics teaching should . . . lead the child from his primary world . . . to the world of science . . . in such a way that *he/she stays rooted* in this primary world where the moon is not simply a gray stone in distant

space, but may be a consolation in the darkness. (Jung 2012, p. 1075, emphasis added)

The genetic approach: from the primary world to the counterintuitive world of science, while staying rooted in the primary world

Readers should not be led to the quick conclusion that science educators generally have used the genetic approach. As the introductory quotations show, finding a way of teaching an idea through a genetic process is as difficult as the originary movement that has led to the idealization at the cultural-historical plane in the first place. The genetic approach is challenging when science educators do not attempt to replace children's primary world but allow the genesis of a new one to occur *organically* in the soil that has rooted the old one. Even though the world of science may be *counter*-intuitive, Jung emphasizes that the world of science should remain rooted in the children's primary world. We already see from the interview fragment featuring Mary that what we learn to say about the universe fundamentally is grounded in the original and originary ways in which we intuit the world: The sun rises, moves across the sky, and sets. Our sense experiences provide us with the foundational sense that are the roots—in the sense of *enracinement*—that found any scientific sense that follows *even when the latter overturns the former*. It is precisely in making us distrust our sense experiences that science education becomes uprooting and leads to *déracinement* (Weil 1990). Although Mary has had lessons in geography and astronomy as part of her early school experiences, her ways of describing the universe generally and the phenomena within the solar system specifically in ways that antedate her science lessons. Some science educators—including those from Mary's own Taiwanese culture—suggest offering experiences that bring about cognitive conflict and conceptual change in students such as Mary (e.g. Liu 2006). The genetic approach, on the other hand, intends providing experiences that lead to *enracinement* in the face of the *déracinement* that scientific revolutions—re-lived at the level of the individual—constitute. That is, only when science education offers a place where students can grow roots because they have become deeply familiar with a phenomenon can they go through the dialectic movement of *déracinement* | *enracinement* that provides them with the safety of a new home while they lost their old.

Science teachers may all too rapidly move to a heliocentric description of the universe. This, as the cited quotation of Weil shows, uproots children and deprives them of their familiar world. The genetic philosophical description and explanation of development has to exhibit the continuity of something from something it is not, for example, from an animistic view to a scientific one. In the same way, the genetic approach to teaching has to emphasize the historical roots of ideas from their incommensurable predecessors, from the absence of objectivity to its opposite. But Galileo himself, celebrated to be an ingenious scientist, acknowledges that the Copernican system is not easy to comprehend. In a marginal note of his text he comments: "*The* Copernican *Systeme difficult to be understood but easie* [sic] *to be effected*" (p. 345, original emphasis). If he considered the Copernican system difficult to apprehend—e.g., on the part of his readers, many of whom, heretofore, have described the universe in Aristotelian/Ptolemaic terms—then we can surely expect similar difficulties to be experienced by those who, at the current time, describe the universe in similar terms. In his text, Galileo describes Copernicus' writing as "obscure" ("I hope by making use of another kind of explanation, than that used by *Copernicus*, to render likewise the apprehending of it somewhat lesse [sic] obscure," p. 345, original emphasis). Teaching understanding does not mean to tell or prove to children (s) that they have to admit, whether or not it makes sense to them, and believe. Genetic teaching means that children can gain insights into why humanity could and can arrive at certain ideas—e.g., because nature offered and continues to offer certain resources for seeing phenomena in this or that way. Thus, for example, Aristotle's insight that the earth must be a sphere, which he took from the shared observational fact that lunar eclipses always leave the same curved shadow on the moon, was also available to Copernicus and Galileo, two of the key personalities during the Renaissance that came to be associated with what is now known as the Copernican (scientific) revolution.

The genetic approach—where the adjective has to be heard as a shorthand for simultaneously being genetic, exemplary/exemplifying, and dialogic (Socratic)—was conceived to allow children and students in science to work through some of the essential *groundbreaking* situations in the sciences all the while allowing them to honor their non-scientific ways of being in the world (Wagenschein 1977). The historical approach to science education, in contrast, emphasizes the introduction of formal concepts through "teachers, books or some other *external* source" (Matthews 2000, p. 284). The genetic approach, although it has a historical dimension, is not *just* historical and distinguishes itself considerably from it in not presupposing the necessity of the scientific concepts that are arising during the genesis of ideas as the (teleological) historical approach does (Fischler 2011). The genetic approach does not conceive of a gap between "students' and targeted scientific models" (Liu 2005, p. 322) to be bridged by means of other scientific models and analogies as a way of "interpreting, organising and transferring the historical material into the instructional apparatus" (p. 322). Instead, the genetic approach is completely rooted in children's commonsense experience of the world (Jung 2012), which children themselves come to overturn in the course of *extended* experiences with a small number of phenomena. Across a number of texts, Wagenschein provides examples and reflections from different fields of inquiry—mathematics, astronomy, and physics—what science educators might consider and do in the attempt to evolve a genetic approach to teaching and learning. The genetic approach allows children and students to move through some of the original constitutions of science that arose on the basis of, using the tools provided by, and focusing on the characteristic objects of a culture at a certain point in time. They do so in a dialogical way, in open conversations among each other and with the teacher. In astronomy, this might be some of the early Greek observations that led to the conception of the earth as a sphere, the first conceptualizations of the relationship between earth and moon, or the evolution of an argument for a heliocentric model, including its now as faulty recognized explanations given by Galileo based on the tides and tidal movement. In the case of physiology, children and students could engage in tasks that allow them to make precisely the kind of observations that led to the first constitution of the function of the heart and circulatory system (e.g., Roth and Friesen 2013a, 2013b).

The genetic approach: an example from astronomy

Following Wagenschein's suggestion to explore astronomical concepts based on children's experiences with the earth ball as ground, I provide the ensuing exemplifying suggestions for a topic in earth science. Wagenschein points out that the point of instruction "is not to eradicate [*ausmerzen*] a 'wrong' original/originary relation between earth and sky, but to associate and superordinate to it a new one, 'to keep it transformed'" (Wagenschein 1988, p. 311). Teaching might begin with the early days of astronomy. In those days, keen observations of the heavens—sun, moon, stars, their movements and changes with movement—without any instrumentation, provided the primary materials for thinking about the earth. The Pythagoreans had indeed thought of the earth as moving, only Aristotle, drawing on keen observation and reasoning, provides a proof for a stationary earth. In his writings, Aristotle does not just fantasize, but grounds what he writes in his own and the accounts of others' experiences. For example, this occurs when he distinguishes between the different forms in which the moon appears in the sky. He appeals to the perceptual senses to provide evidence supporting the hypothesis of a spherical earth: "How else would the eclipses of the moon have the sections of the circle? (Aristotle 1560, p. 41, r). Thus, "an eclipse always has a curved line, which distinguishes it" (p. 41, r). He distinguishes the shape of the shadow during lunar eclipses with the shape of the moon as seen in the course of a lunar month when it is straight, gibbous, and concave.

Already in Aristotle's days, the curvature of the earth—that it is round and of small/unimportant magnitude [*parua magnitudo*]—was derived from keen observations that can be made while traveling:

> If we move even a little to the south or north, a different horizon [*finiens orbis*, literally end of the world] shows itself, and in the stars overhead there is a considerable change, and the stars are seen differently when going a little to the north or south. Because some stars that are seen in Egypt and in Cyprus are not seen in northerly directions: and stars that in northerly locations can always be seen, there go down/set [*occidunt*]. (Aristotle 1560, p. 41, v)

Copernicus later makes the same argument as Aristotle about the spherical nature of the earth, which has to be round because all masses press towards the center. He makes precisely the same argument as Aristotle based on the fact that certain stars are seen in the north but not seen in the south and the reverse. Just like Aristotle, he draws on specific observations, talking about starts that are permanently seen in the north whereas they are not even rising in the south. He draws on the same observation and description as Aristotle in his argument that the earth is a perfect sphere.

> *Talem quippe figurã habere terram cum circumfluentibus aquis necesse est, qualem umbra ipsius ostendit: absoluti enim circuli circumferentijs Lunã deficiẽtem efficit* [From this it is obvious that the shape of the earth and the surrounding water has to be, as its shadow shows: it eclipses the Moon with absolutely circular circumferences (arcs)]. (Copernicus 1543, p. 2r)

The astronomer then moves to introduce relative motion into the argument, whereby the movement of the object or the movement of the observer may produce an object's observed changes of place. This observation also is familiar to the moderns driving a car, or sitting in a train, where, when, for example, reading a book, our train appears to be leaving the station when in fact the train on the next track is moving while our train remains still.

> *Iam quia demonstratum est, terram quod globi formam habere, uidendum arbitror, an etiam formam eius sequantur motus, & quem locum uniuersitatis obtineat, sine quibus non est inuenire certam apparentium in cœlo rationem* [Now that it has been demonstrated that the earth has the form of a globe I have to also show whether its form follows motion and what place it has in the universe, without which it is impossible to discover the certain reason of what is to see in the heavens]. (Copernicus 1543, p. 3r)

It is this part of Copernicus' move that may become a central aspect to teaching astronomy according to the genetic approach. Children may discuss and try out relative motion, when they move with respect to others or others move while they remain at rest:

> *Omnis enim quæ uidetur secundum locum mutatio, aut est propter spectatæ rei motum, aut uidentis, aut certe disparem utriusque mutationem. Nam inter mota æqualiter ad eadem, non perceptitur motus, inter rem uisam dico, & uidentem* [For every apparent change in place occurs by the movement either of the thing seen, or by the observer, or by the necessarily unequal change of both. For when things move equally in the same direction, no movement is perceptible relatively to things moved equally in the same direction, I mean between the thing seen and the observer]. (Copernicus 1543, p. 3r)

In this quotation, we see how Copernicus introduces relative motion between the observer and the thing seen, a phenomenon that Galileo later will take on in his work on the subject (Fig. 2) and the addition of velocities. In fact, Copernicus did not claim to have been at the origin of this idea. In the foreword to his book, addressed to the reigning pope, Galileo clearly attributed the idea of the moving earth to the Pythagoreans, who made the earth move. "The opportunity having arisen from this, I began and I considered of the movement of the earth" (Copernicus 1543, p. iv, r).

«««« Insert Fig. 2 about here »»»»

Fig. 2. In his *Dialogue*, Galileo (1661) includes a diagram that is described, in his own words, as "A plain scheme representing the *Copernican* hypothesis and its consequences" (p. 355). He had in fact borrowed the diagram and further enhanced from the original text by Copernicus (1543).

It is precisely that shift from considering relative motion of object and observer that presupposes the phenomenon of movement, which itself is the observation of something in motion with respect to something at rest. This observation is even more originary and, therefore, the very condition for the subsequent change to a scientific description of relative motion. Cultural-historically, this shift only occurred in the sciences rather recently, during the Renaissance. It constitutes a tremendous shift in which the earth-ground becomes merely another object. It means in fact that the children and students have to uproot, give up the position in their familiar primary world, and now look upon the earth, sun, moon, and planets from the outside. This outside may in fact be considered a new ground, a new world. But its possibility rests on the primary earth-ground, which is both abandoned and kept in the transition, sedimented in the very possibility of considering objects once we are *enraciné* in some ground. Without that primary ground nothing happens, and a total disorientation sets in. That is, if astronomical (science) education does not provide for an *enracinement*, then students lose their old ground without gaining a new one on the basis of which to understand both their old and new ways of considering an object or phenomenon.

Wagenschein (1977) suggests that children and students of science do not have to learn every topic that currently populates the science curriculum. Instead, closely investigating a few topics—such as the historical transition from a geocentric to a heliocentric conception of the solar system—allows them to live through again (*Nacherleben*), complete a conceptual movement again (*Nachvollziehen*), and produce again (*Nacherzeugen*) (Roth and Friesen 2013b), in active and passive synthesis, the crucial transition from an earlier to a later worldview in the way that Husserl (1976) theorized it. Those few experiences serve in exemplifying ways and, in a part–whole relation, reflect the entire universe of science in one drop of rain (a small number in any case).

Conclusion: the genetic approach and the dialectic of déracinement | enracinement

> The notion of *Enracinement* appears central to me for Formation and the genetic principle of education: . . . being rooted, and remaining rooted, within the encompassing primary environment. (Wagenschein 1977, p. 59)

In an article on Wagenschein's genetic approach, Jung (2012) refers to the opening quotation as representing its essence. In the present article, I describe (a) how science education can be thought in terms of the dialectic of *déracinement | enracinement* and (b) an approach to science education that aims at preventing the sense of alienation many students experience when asked to abandon their primary world. *The earth moves; yet it does not move*—the dialectic of *déracinement* (brought about by the moving earth) and *enracinement* (brought about by the earth that does not move) is captured precisely in this incompossible statement. For the earth to be able to move, it has to be foundationally at rest. For science to evolve, there has to remain firm ground on which it rests. Too often, however, science students do not have the opportunity to become familiar with a topic or phenomenon to regrow roots in a soil that becomes a new home, in an extension of the roots from old to new ground, from a primary earth that does not move to a scientific earth that moves. The genetic approach—which I ground here in the commensurable phenomenological philosophy apparently unfamiliar to Wagenschein—emphasizes this dialectic or uprooting and re-rooting. I denote this dialectical process here by means of S. Weil's French concept words *déracinement* and *enracinement* that also had served Wagenschein as an anchoring ground for his ideas for a more appropriate science education. Critical science educators may easily buy into Wagenschein's approach, for it allows "to demystify the current scientific doctrine (at least in schools) in order to popularize science by empiricocritical teaching of its genetic process" (Siemsen 2010, p. 304).

Many science concepts are counterintuitive (Vosniadou 2013). Science, in telling students that they have to distrust their intuitions and common sense, is experienced as uprooting and alienating (Wagenschein 1988; Weil 1990). This conceptualization is consistent with the fact that so many students—often women, aboriginal, and others with firm roots in everyday ways of understanding the world—drop, and drop out of, science. But science education can be different. The tremendous learning that has been observed among female, aboriginal, and "learning *dis*abled" students (e.g. Roth and Barton 2004; Roth et al. 1999) becomes intelligible, here, in a new way: These students were not only working on familiar grounds, a creek in their community or machines that they themselves designed and made to work, but also had opportunities to grow roots in new grounds as they developed ways of investigating, designing, and describing phenomena in ways consistent with Western science. In the process of *déracinement* | *enracinement,* these students grew new roots upon their old ones. Having had the opportunity to design their own projects, based on what made sense to them, and pursue these projects to a great depth over 4–5 months periods, is precisely what the genetic approach is about: to organize itself around the development of each individual student.

The genetic approach—not in the least because it is also dialogical and exemplary/exemplifying (i.e., paradigmatic)—fundamentally is cultural-historical. Children and older science students come to engage in the very processes that allow the tradition (in the sense of handing on) of science, which occurs when they re-live the original creation and evolution of scientific sense, both enracined in and uprooting from an original earth-ground. In dialogical relations, where teachers, students, and others present in the classroom (e.g., coteaching new teachers, researchers, supervisors) may develop curriculum, talking science, and relating to each other in new ways—as this has already been studied in coteaching | cogenerative dialoguing (e.g., Roth et al. 2002). The historical presence of science—including its gendered nature (e.g. Lederman and Bartsch 2001)—derives from the totality of human history, and each new understanding act and understanding conception is rooted (*enracined*) in the fundamentally pre-scientific world on both cultural-historical and ontogenetic levels. For, "do we not know that the present and the total historical time implied in it is the age of a historical unified-unitarian *humanity*, unitary through its generative connections and continuous collectivization in cultivating from always already cultivated?" (Husserl 1939, p. 222). The figure of cultivation, of course, is related to the figure of *enracinement* | *déracinement*, as every gardener or farmer knows. Without the ability to set roots, nothing grows; and what is uprooted (e.g. weeds) dies. For many plants that can in fact be transplanted, disturbing the roots as little as possible—leaving the clump surrounding the young plants undisturbed—allows these to push from the clump into the surrounding soil and, thereby, become anchored in the new ground without having the old clump removed. As the innovative elementary teacher Bernard Collot in the French village of Moussac suggested, "The gardener's . . . problem is to put [plants] at their right spot, to plant them somewhere, to recognize that this might not be the right place, and to replant them somewhere else" (Roth 2002, p. 47). When that garden is in order, when it really works, then '"children inevitably learn" (p. 47). He was building his teaching on the ideas of the French educator C. Freinet, who had emphasized learning in the local milieu familiar to the children and the importance of connecting school to everyday life (Freinet 1921). In his words, "we continue to treat children like machines that one feeds with indigestible materials" (p. 126). The genetic approach, with its attention to extended depth in the familiar surroundings of the children rather than shallow breadth, lends itself to cross-curricular integration. For example, *De Revolutionibus* (Copernicus 1543) contains a lot of geometrical argumentation, lending itself to integration with mathematics. The conversational form of the *Dialogues* (Galileo 1661) and the argumentative manner of presenting alternative worldviews contained in it provides opportunities of literary analysis generally and of the genre forms specifically, including the argumentative methods currently en vogue in science education. For the small number of students taking Latin classes, many original texts in that language are easily available online.

Acknowledgments

The collection of the data from which the featured fragment was extracted was made possible by a grant from the Natural Sciences and Engineering Research Council of Canada. I thank Pei-Ling Hsu for her assistance.

References

Aikenhead, G., & Ogawa, M. (2007). Indigenous knowledge and science revisited. *Cultural Studies of Science Education, 2,* 539–591.
Arendt, H. (1958). *The human condition*. Chicago: University of Chicago Press.
Aristotle (1560). *De cælo* [Of the heavens]. Paris: Gabrielis Buon.
Australian Academy of Science (2013). PrimaryConnections: Linking science with literacy. Accessed September 25, 2013 at http://primaryconnections.org.au/indigenous/

Brandt, C. B. (2008). Discursive geographies in science: space, identity, and scientific discourse among indigenous women in higher education. *Cultural Studies of Science Education, 3,* 703–730.
Châtelet, G. (1993). *Les enjeux du mobile: Mathématique, physique, philosophie* [The stakes of movement: Mathematics, physics, philosophy]. Paris: Éditions du Seuil.
Copernicus, N. (1543). *De revolutionibus orbium cœlestium* [On the revolutions of the celestial spheres]. Nuremberg: J. Petreius.
Deleuze, G., & Guattari, F. (1972/1973). *Capitalisme et schizophrénie: Anti-Œdipe* [Capitalism and schizophrenia: Anti-Oedipus:]. Paris: Les Éditions de Minuit.
Deleuze, G., & Guattari, F. (1980). *Capitalisme et schizophrénie: Mille plateaux* [Capitalism and schizophrenia: A thousand plateaus]. Paris: Les Éditions de Minuit.
Derrida, J. (1990). *Le problème de la genèse dans la philosophie de Husserl* [The problem of genesis in the philosophy of Husserl]. Paris, France : Presses Universitaires de France.
Derrida, J. (1996). *Le monolinguisme de l'autre Ou la prothèse de l'origine* [Monolingualism of the other Or prosthesis of origin]. Paris: Éditions Galilée.
Dewey, J. (2008). *The later works, 1925–1953 vol. 13: 1938–1939: Experience and education, Freedom and culture, Theory of valuation, and Essays* (J. A. Boydston, ed.). Carbondale, IL : Southern Illinois University Press.
Dunlop, J. (2000). How children observe the universe. *Publications of the Astronomical Society of Australia, 17,* 194–206.
Fanetti, T. M. (2001). *The relationships of scale concepts on college age students' misconceptions about the cause of the lunar phases*. Unpublished MA thesis, Ames, IA. Accessed September 28, 2013 at http://physicseducation.net/members/Fanetti.pdf
Fischler, H. (2011). Didactic—An appropriate framework for the professional work of science teachers. In D. Corrigan, J. Dillon, & R. Gunstone (Eds.), *The professional knowledge base of science teaching* (pp. 31–50). Dordrecht: Springer.
Freinet, C. (1921, May 7). Comment rattacher l'école à la vie [How to connect school with life]. *École Émancipée, 32*, 126. Accessed March 3, 2014 at http://www.amisdefreinet.org/archives/ecoleemancipee/19210507.html
Galileo, G. [Galileus Galileus Linceus] (1661). The system of the world in four dialogues. In T. Salusbury (Ed.), *Mathematical collections and translations vol. 1* (1–425). London: William Leybourne.
Garfinkel, H. (2002). *Ethnomethodology's program: Working out Durkheim's aphorism*. Lanham, NY: Rowman & Littlefield.
Heidegger, M. (1977). *Sein und Zeit* [Being and time]. Tübingen: Max Niemeyer.
Heywood, D., Parker, J., & Rowlands, M. (2013). Exploring the visuospatial challenge of learning about day and night and the sun's path. *Science Education, 97*, 772–796.
Husserl, E. (1939). Die Frage nachdem Ursprung der Geometrie als intentional-historisches Problem [The question of the origin of geometry as intentional-historical problem]. *Revue internationale de philosophie, 1,* 203–225.
Husserl, E. (1940). Grundlegende Untersuchungen zum phänomenologischen Ursprung der Räumlichkeit der Natur [Foundational investigations of the phenomenological origin of the spatiality of nature] In M. Farber (Ed.), Philosophical essays in memory of Edmund Husserl (pp. 307-325). Cambridge, MA: Harvard University Press.
Husserl, E. (1946). Die Welt der lebendigen Gegenwart und die Konstitution der außerleiblichen Welt [The world of the living present and the constitution of the surrounding world]. *Phenomenology and Phenomenological Research, 6,* 323–343.
Husserl, E. (1976). *Husserliana Gesammelte Werke Band VI: Die Krisis der europäischen Wissenschaften und die transzendentale Phänomenologie. Eine Einleitung in die phänomenologische Philosophie* [Husserliana collected works vol. 6: The crisis of the

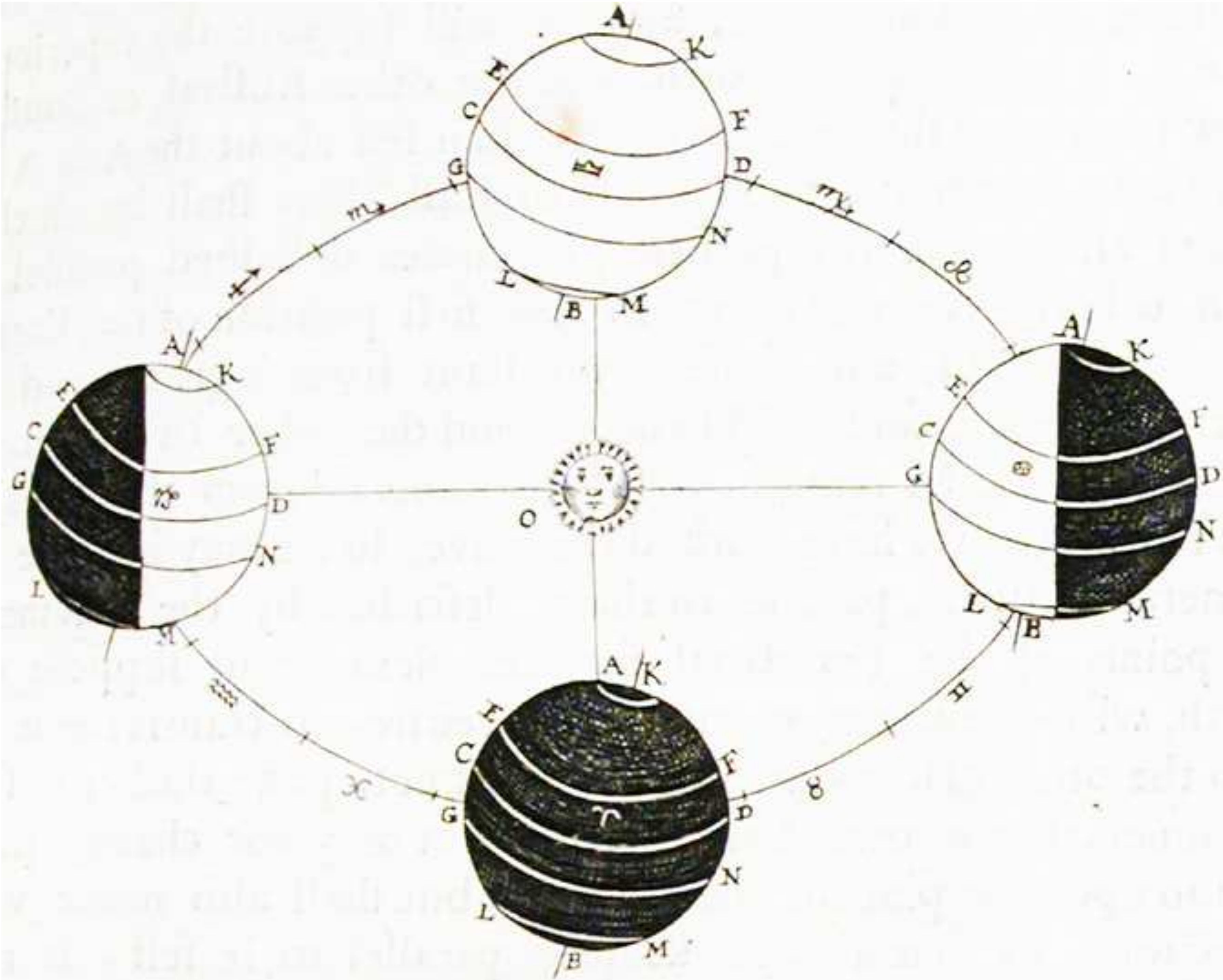
European sciences and transcendental phenomenology: An introduction to phenomenological philosophy]. The Hague: Martinus Nijhoff.
Jung, W. (2012). Philosophy of science and education. *Science & Education, 21,* 1055–1083.
Lederman, M., & Bartsch, I. (Eds.). (2001). *The gender and science reader*. London: Routledge.
Liu, S.-C. (2005). Models of the "heavens and the earth"" An investigation of German and Taiwanese students' alternative conceptions of the universe. *International Journal of Science and Mathematics Education, 3,* 295–325.
Liu, S.-C. (2006). From geocentric to heliocentric model of the universe, and the alternative perspectives. *Asia-Pacific Forum on Science Learning and Teaching, 6*(2). Accessed September 29, 2013 at http://www.ied.edu.hk/apfslt/v6_issue2/liusc/
Lucas, K. B., & Roth, W.-M. (1996). The nature of scientific knowledge and student learning: Two longitudinal case studies. *Research in Science Education, 26*, 103–129.
Luria, A. R. (1979). *The making of mind: A personal account of Soviet psychology*. Cambridge, MA: Harvard University Press.
Marion, J.-L. (1996). *La croisée du visible* [Crossing of the visible]. Paris: Presses Universitaires de France.
Matthews, M. R. (2000). *Time for science education: How teaching the history and philosophy of pendulum motion can contribute to science literacy*. New York: Kluwer Academic/ Plenum Publishers.
Merleau-Ponty, M. (1964). *Le visible et l'invisible* [The visible and the invisible]. Paris: Gallimard.
Merleau-Ponty, M. (2002). *Husserl at the limits of phenomenology (including texts by Edmund Husserl)*. Evanston, IL: Northwestern University Press.
Mpofu, V., Otulaja, F. S., & Mushayikwa, E. (2013). Towards culturally relevant classroom science: a theoretical framework focusing on traditional plant healing. *Cultural Studies of Science Education*. DOI: 10.1007/s11422-013-9508-5
Nam, Y. (2012). Rethinking historical and cultural source of spontaneous mental models of water cycle: in the perspective of South Korea. *Cultural Studies of Science Education, 7,* 485–493.
Østergaard, E., Dahlin, B., & Hugo, A. (2008). Doing phenomenology in science education: a research review. *Studies in Science Education, 44,* 93–121.
Patronis, T., & Spanos, D. (2013). Exemplarity in mathematics education: from a Romanticist viewpoint to a modern hermeneutical one. *Science & Education, 22*, 1993–2005.
Reuell, P. (2013, April 30). Understanding student weakness. Harvard Gazette. Accessed September 28, 2013 at http://news.harvard.edu/gazette/story/2013/04/understanding-student-weaknesses/
Rorty, R. (1989). *Contingency, irony, and solidarity*. Cambridge: Cambridge University Press.
Roth, W.-M. (2002). Learning in Moussac. In L. M. Richter & R. Engelhart (Eds.), *Life of science: Whitebook on educational initiatives in natural sciences and technology* (pp. 45–55). Copenhagen: Learning Lab Denmark.
Roth, W.-M. (2008). Bricolage, métissage, hybridity, heterogeneity, diaspora: Concepts for thinking science education in the 21st century. *Cultural Studies in Science Education, 3*, 891–916.
Roth, W.-M. (2012a). Mathematical learning: the unseen and unforeseen. *For the Learning of Mathematics, 32*(3), 15–21.
Roth, W.-M. (2012b). Through the eyes of the learner. *Éducation & Didactique, 6*, 129–142.
Roth, W.-M. (2013). To event: Towards a post-constructivist approach to theorizing and researching curriculum as event*-in-the-making. *Curriculum Inquiry, 43*, 388–417. doi: 10.1111/curi.12016

Roth, W.-M. (in press). Learning in the discovery sciences: The history of a "radical" conceptual change or The scientific revolution that was not. *Journal of the Learning Sciences*. DOI: 10.1080/10508406.2014.893435
Roth, W.-M., & Barton, A. C. (2004). *Rethinking scientific literacy*. New York: Routledge.
Roth, W.-M., & Friesen, N. (2013a). History and the relationship between scientific and pedagogical knowledge: anatomy lectures then and now. *Journal of Curriculum Studies*. doi: 10.1080/00220272.2013. 773597
Roth, W.-M., & Friesen, N. (2013b). *Nacherzeugung, Nachverstehen*: a phenomenological perspective on how public understanding of science changes by engaging with online media. *Public Understanding of Science.* DOI: 10.1177/0963662513512441
Roth, W.-M., & Jornet, A. (2013). Towards a theory of *experience*. *Science Education.* DOI: 10.1002/sce.21085
Roth, W.-M., & Lawless, D. (2002). Scientific investigations, metaphorical gestures, and the emergence of abstract scientific concepts. *Learning and Instruction, 12,* 285–304.
Roth, W.-M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education, 88*, 263–291.
Roth, W.-M., Lee, Y. J., & Hwang, S.-W. (2008). Culturing conceptions: From first principles. *Cultural Studies of Science Education, 3*, 231–261.
Roth, W.-M., McGinn, M. K., Woszczyna, C., & Boutonné, S. (1999). Differential participation during science conversations: The interaction of focal artifacts, social configuration, and physical arrangements. *Journal of the Learning Sciences, 8*, 293–347.
Roth, W.-M., Tobin, K., & Shaw, K. (1997). Cascades of inscriptions and the re-presentation of nature: How numbers, tables, graphs, and money come to re-present a rolling ball. *International Journal of Science Education, 19*, 1075–1091.
Roth, W.-M., Tobin, K., Zimmermann, A., Bryant, N., & Davis, C. (2002). Lessons on/from the dihybrid cross: An activity theoretical study of learning in coteaching. *Journal of Research in Science Teaching, 39*, 253–282.
Schoultz, J., Säljö, R., & Wyndham, J. (2001). Heavenly talk: discourse, artifacts, and childrens' understanding of elementary astronomy. *Human Development, 44*, 103–118.
Seely, R. (2012, October 18). Seely on science: UW researcher to study why students drop out of science. *Wisconsin State Journal*. Accessed September 25, 2013 at http://host.madison.com/news/science/seely-on-science-uw-researcher-to-study-why-students-drop/article_dad880da-194e-11e2-bc08-001a4bcf887a.html
Sheets-Johnstone, M. (2011). *The primacy of movement 2nd ed.* Amsterdam: John Bemjamins.
Siemsen, H. (2010). The Mach-Planck debate revisited: democratization of science or elite knowledge? *Public Understanding of Science, 19*, 293–310.
Tabarrok, A. (2012, March 4). Turning in to drop out. *The Chronicle of Higher Education*. Accessed September 25, 2013 at http://chronicle.com/article/Tuning-In-to-Dropping-Out/130967/
van Eijck, M., & Roth, W.-M. (2009). Authentic science experiences as a vehicle to change students' orientation towards science and scientific career choices: Learning from the path followed by Brad. *Cultural Studies of Science Education, 4*, 611–638.
Van Eijck, M., & Roth, W.-M. (2010). Towards a chronotopic theory of "place" in place-based education. *Cultural Studies of Science Education, 5*, 869–898.
Vološinov, V. N. (1930). *Marksizm i folosofija jazyka: osnovye problemy sociologičeskogo metoda b nauke o jazyke* [Marxism and the philosophy of language: Main problems of the sociological method in linguistics]. Leningrad, USSR: Priboj.
Vosniadou, S. (2013). Model based reasoning and the learning of counter-intuitive science concepts. *Infancia y Aprendizaje, 36,* 5–33.

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science, 18,* 123–183.
Vygotskij, L. S. (2005). *Psyxhologija razvitija čeloveka* [Psychology of human development]. Moscow: Eksmo.
Wagenschein, M. (1977). *Verstehen lehren: Genetisch—Sokratisch—Exemplarisch* [Teaching understanding: Genetically—Socratically—exemplary]. Weinheim: Beltz.
Wagenschein, M. (1988). *Naturphänomene sehen und verstehen—Genetische Lehrgänge* [Seeing and understanding natural phenomena—Genetic teaching]. Stuttgart: Klett.
Weil, S. (1990). *L'enracinement* [The rooting]. Paris: Gallimard.

Colour Figure
Click here to download high resolution image

Colour Figure
Click here to download high resolution image



Wolff-Michael Roth is Lansdowne Professor of applied cognitive science at the University of Victoria. His research concerns the learning of science and mathematics across the life span. His most recent works include **What more in/for Science Education: An Ethnomethodological Perspective** (Sense, 2013), **First person methods: For a rigorous approach to the study of lived experience** (Sense Publishers, 2012), **Passibility: At the limits of the constructivist metaphor** (Springer, 2011), **Geometry as objective science in elementary classrooms: Mathematics in the flesh** (Routledge, 2011), and, with L. Radford, **A cultural-historical perspective on mathematics teaching and learning** (Sense Publishers, 2011).