THE THEORY OF TOTALLY INTEGRATED EDUCATION: TIE

Theodore W. Frick

Professor Emeritus

Department of Instructional Systems Technology

School of Education, Indiana University Bloomington

frick@iu.edu (last revised November 14, 2023)

Now published:

Frick, T.W. (2023). The Theory of Totally Integrated Education (TIE) . In: Spector, M.J., Lockee, B.B., Childress, M.D. (eds) *Learning, Design, and Technology*. Springer, Cham. https://doi.org/10.1007/978-3-319-17727-4_69-3

Abstract

The Theory of Totally Integrated Education (TIE) predicts that mental structures formed by learners are expected to be stronger when 'knowing that one', 'knowing how', and 'knowing that' are integrated with learner emotions and intentions. Such whole, completely connected mental structures are expected to be less vulnerable to forgetting. TIE theory builds on seminal work of John Dewey, Charles Sanders Peirce, Maria Montessori, Elizabeth Steiner, George Maccia, Stanley Greenspan, Kenneth Thompson, Myrna Estep, Eric Kandel, David Merrill, and Jeroen van Merriënboer. Two unique extant cases of education systems are described which illustrate parts of TIE theory. A further strategy for improving curriculum is recommended, which is based on sequencing authentic, whole learning tasks from simple to complex. Most importantly, these learning tasks are expected to help students integrate nine kinds *cognition* with emotions and intentions: recognitive,

acquaintive, appreciative, protocolic, adaptive, creative, instantial, relational, and criterial. A variety of teaching methods can be used to implement such an improved curriculum. TIE theory does not prescribe specific instructional methods or practices; rather it provides a set of principles which can be used to evaluate curriculum itself. To the extent these principles are present in curriculum, TIE theory predicts that students are more likely to achieve curriculum goals.

Key words

Integration of cognition, emotion, and intention; holistic teaching and learning; definition of kinds of learning; educational theory; systems theory

1. An overview of TIE theory

The big picture

I have taken classes in school where I was constantly asking myself: Why do I need to learn this stuff? This is so boring. I wish I were doing something else.

Every once in a while, I was lucky to take a class that was terrific. My teacher was excellent. I was totally involved, completely immersed. I could not learn enough. This learning was very important to me.

So, what was the difference between those boring classes I took and ones that were really great? In this chapter, I explain why we learn a lot more in some situations compared with others.

First, emotion is important for learning and memory. Many people remember highly emotional experiences. They can usually tell you in great detail about a particularly thrilling, highly stressful, or a frightening experience—even if it occurred a long time ago.

For example, I can still vividly recall when I was about 6 years old, I was riding my bicycle along the right side of the state highway on my way home. A boy next door yelled across the road, asking me to come over to his house to play. I started to turn left across the road, but quickly turned back to the side berm when I heard brakes screeching right behind me. A big truck stopped suddenly just in time to keep from running over me. And then several cars going too fast and following too closely behind the truck crashed into each other—a chain-level collision.

I was really scared. I could have been run over and crushed by the semi. A policeman later came to my house and asked me questions about what happened. I was afraid he would arrest me and that I would go to jail because I caused an accident. But he did not.

I still clearly remember this traumatic event, more than 60 years ago.

Emotions structure memories

Emotions organize and give meaning to experience. "They can, therefore, serve as the architect or orchestra leader for the mind's many functions" (Greenspan & Shanker, 2004, location 658).

Stanley Greenspan, a medical doctor with decades of clinical experience in treating autism, repeatedly observed that human emotion while engaging in an activity or while interacting with another person creates the architecture of that person's mental structure.

The dual coding of sensations and emotions arising from those experiences organize one's mental structure.

There is further evidence from molecular biology that supports Greenspan and Shanker's claim. Kandel (1989), a Nobel-prize winning neuroscientist, claimed that "evidence suggests that learning produces enduring changes in the structure and function of synapses…" (p. 121). He recommended further study on "the *power of experience* in modifying brain function *by altering synaptic strength*…" (p. 123, italics added).

According to Eagleman (2015), when we are born we each have approximately 100 billion neurons in our nervous system. During the first 2-3 years of life, our body creates trillions of connections among those neurons. As we further grow, develop, and learn, our individual experiences literally prune those connections, so that the remaining connections form a unique mental structure, the unique long-term memories we each have. Certain connections are strengthened through those experiences throughout our lives, and other connections are weakened.

Emotions arising during life experience apparently strengthen certain connections (synapses) among neurons, forming the architecture of each of our minds. Greenspan and Benderly (1997) have noted that since the ancient Greek philosophers, the rational or cognitive aspect of mind has often been viewed as developing separately from emotion. They argue that this view has blinded us to the role of emotion in how we organize what we have learned: "In fact, emotions, not cognitive stimulation, serve as the mind's primary architect" (p. 1).

Greenspan and Benderly (1997) identify the importance of emotion during human experience: "… each sensation … also gives rise to an affect or emotion…. It is this dual coding of experience that is the key to understanding how emotions organize intellectual capacities …" (p. 18).

The theory of Totally Integrated Education (TIE) builds on these fundamental premises.

Why TIE theory?

Why is it that the majority of U.S. high school students are bored every day in school? Yazzie-Mintz (2007) summarizes results from a survey of 81,499 students in 110 high schools across 26 U.S. states. Approximately 2 out of 3 students said that they were bored in class every day. When asked why they were bored, the top reasons were that learning materials were uninteresting, irrelevant and not challenging enough. Yazzie-Mintz cited one student who stated, "Our school needs to be more challenging. Students fall asleep because the classes aren't really that interesting." Another said, "School is easy. But too boring. Harder work or more is not the answer though. More interesting work would be nice" (p. 10).

Students who considered dropping out of school indicated that the main reasons are dislike of their school and teachers. Sixty percent further said, "I didn't see the value in the work I am asked to do" (p. 5). For those who stay in school, the primary reason they do so is to get their high school diploma, so that they can go on to college.

Likewise, many of us have experienced taking classes in our formal education, or even on the job, during which we were thinking to ourselves, "Who cares about this subject? This is so boring. I am wasting my time."

Every once in a while, we may have been fortunate take that rare class or course that was terrific. Our teacher was so inspiring. We spent hours absorbed completely, unaware of the passage of time.

So, what was the difference between the former and latter experiences, from the point of view of the student—an utter waste of time versus experiencing elation, flow, and wanting to learn more? The theory of Totally Integrated Education (TIE) aims to explain why. More importantly, TIE theory should help parents, teachers, curriculum developers and instructional designers to create student learning experiences which more often result in the latter situation.

Students will be thankful. Especially those who have to go to a place called school or college. Also, students who are learning on the job outside of a formal educational setting called school will be thankful.

TIE theory development through retroduction and deduction

Thompson (2006b) emphasized that the value of new theory is to predict the unknown:

> … the purpose of a theory is to provide the means to develop mathematical, analytical, or descriptive models that predict counterintuitive, nonobvious, unseen, or difficult-to-obtain outcomes. When all we are testing are outcomes that are preconceived, then we

> are missing the very purpose of scientific inquiry—to determine what it is that we do not know, rather than that which we have just not yet confirmed, or patterns that we have just not yet discerned. Confirmation of a hypothesis may be interesting and of limited value, but to call a body of knowledge that does nothing more than confirms perceptions of known events is to trivialize the notion of theory to the point where any proclamation becomes a theory. (p. 16)

Thompson (2006b) provides an example of how quantum mechanics theory in physics has predicted unexpected, counterintuitive outcomes:

> Possibly the best example of theory development and results comes from quantum mechanics that has predicted so many counterintuitive events. The *Josephson Effect*, a quantum-mechanical effect in superconductors, is a specific example from physics. Holding two superconductors close to each other, there is a coupling of the quantum mechanical wave functions between them. The equations governing the theory of superconductivity predicted this coupling and laboratory testing quickly confirmed the prediction…. Voltage standards, highly-sensitive microwave detectors, high-density computer circuits and nanotechnologies, generally, have been developed with reliance on the *Josephson Effect*. Here, the theory predicted non-obvious outcomes, the very purpose of a theory. (p. 16)

New theory is not developed in a vacuum. Previous knowledge, experience, and observations do play a role, but use of *other* extant theories via retroduction is also needed. Steiner (1988) argued that development of new theory cannot be done by inductive logic alone. Inductive reasoning is important when verifying theory, but *retroduction* is needed for creating new theory. Steiner (1988, p. 97) cites Peirce (1934) who specified the logic of retroductive inference:

1. The surprising phenomenon, *C*, is observed; and
2. but if *A* were true, *C* would be a matter of course;
3. hence, there is a reason to suspect that *A* is true. (*Collected Papers*, 5.189)

Steiner referred to the "theory models" approach with respect to retroductive inference. To illustrate the significance of retroduction and its application, Maccia and Maccia (1966) developed new educational systems theory through use of the SIGGS theory model which was retroduced initially from set, information, graph, and general system theories. Through retroduction and deduction, the SIGGS theory model was used to devise new educational theory, that consisted of 201 hypotheses. Thompson (2006a, b; 2008a, b) has further developed Axiomatic Theory of Intentional Systems (ATIS), that built upon the SIGGS theory model. The website at https://siggs.sitehost.iu.edu/edutheo.html provides definitions of terminology in the SIGGS theory model with illustrations and examples. ATIS is explicated at: http://educology.indiana.edu/Thompson/index.html.

So, where did the theory of *Totally Integrated Education* come from? There were several key sources.

First, the idea that creation of new 'mental structures' are the result of learning was critical (Greenspan & Benderly, 1997; Kandel, 1989, 2001; Squire and Kandel, 1999; Steiner, 1988). Structures can be represented through digraph theory (e.g., Brandes & Erlebach, 2005; Maccia & Maccia, 1966; Thompson, 2008b). Kandel (1989, 2001) demonstrated that when learning occurs, new connections are formed in the nervous system via chemical strengthening of synapses. Long-term memory is enabled through these strengthened synaptic connections. The nervous system can be represented by a digraph, i.e., the unique network of connections among nerve cells.

Systems theory was also a very important model that heavily influenced TIE theory. The notion of affect relations (connections among system components) and properties of affect-relation sets in systems was central (from SIGGS and ATIS). The structural properties 'strongness', 'wholeness', and 'integration' were key ideas. In the SIGGS theory model (Maccia & Maccia, 1966), 22 structural properties are defined, including for example:

- "Complexness is the number of connections" (p. 62).
- "Flexibleness is different subgroups of components through which there is a channel between two components with respect to affect relations" (p. 59).
- "Strongness is not complete connectedness and *every two components are channeled to each other* with respect to affective relations" (p. 54, italics added).
- "Complete connectionness is every two components *directly* channeled to each other with respect to affect relations" (p. 54, italics added).
- "Wholeness is components which have channels to *all other* components" (p. 58, italics added).
- "Integrationness is [maintenance of] wholeness under system environmental change" (p. 58, brackets added).
- "Vulnerableness is some connections when removed produce disconnectivity with respect to affect relations" (p. 56).

- "Disconnectionness is not either complete connectedness or strongness or unilateralness or weakness and *some components are not connected* with respect to affect relations" (p. 55, italics added).[1]

In particular, the notion of increasing system 'complexness' is the foundation for the definition of 'learning' [and consistent with Kandel's (1989) neurological findings]. The notion of 'forgetting' was retroduced as decreasing system complexness, i.e., some connections are broken and no longer exist.

Most importantly, the central ideas in TIE theory are system 'wholeness' and greater 'flexibility'. Deductively, when each component has two or more connections to every *other* component, it follows that such a network is less vulnerable when compared to a weakly or unilaterally connected network. That is, when some connections are broken, 'wholeness' of long-term memory can still be maintained. Also, through deduction, 'completely-connected' component sets should provide greater flexibleness, i.e., because many different pathways exist between individual components. As an analogy, think of a spider's web—when nodes are highly interconnected, small tears in a few places will not destroy the whole web, and allow a spider to make quick repairs.

Therefore, to the extent wholeness among component sets is maintained or increased, then vulnerableness should decrease—forgetting of what has been learned is less likely. Thus, the retroductive prediction is that learning activities which increase wholeness

[1] See https://siggs.sitehost.iu.edu/ for definitions and examples of 77 system properties in the SIGGS Theory Model (Maccia & Maccia, 1966). Building on SIGGS, Thompson (2006a, b; 2008a, b) has further developed, refined and defined Axiomatic Theories of Intentional Systems (ATIS). See http://aptac.sitehost.iu.edu/glossary/ and http://aptac.sitehost.iu.edu/glossary/atisTheory.html.

in student mental structures should be more effective with respect to student learning (and not forgetting). Totally integrated education should maximize strong connections among kinds of knowing (cognition), intention (conation), and feelings (emotion). Student learning which occurs during totally integrated education should result in more stable long-term memory, less likely to be forgotten as time passes.

A further key idea in TIE theory came from epistemological theory, in particular, Maccia's identification of qualitative, quantitative and performative knowing as being distinctive kinds of cognition (Maccia, 1986, 1987, 1988; Estep, 2006; Frick, 1997; Steiner, 1988). Again, this stimulated the idea that, if these three kinds of knowing are interconnected, this greater integration among kinds of knowing would further contribute to increased wholeness of mental structures.

And finally, TIE theory predicts that integration of emotion, intention, and cognition through teaching and learning activities is expected to contribute to increased interconnectivity (i.e., strongness) of mental structures. Moreover, the roles of emotion and intention as critical elements to strengthening mental structures, according to the work of Greenspan and Benderly (1997), has contributed to the retroduction of TIE theory.

When taken together these theoretical ideas have led to the definitions of terms and schemas represented in Section 2, Figures 1-6. To my knowledge, this leads to a new prediction that has not been empirically tested in educational research. TIE theory predicts that, to the extent all these elements are integrated in teaching and learning activities, student mental structures will be stronger and less vulnerable to forgetting as time passes. A series of experiments can be designed, where disconnectivity is systematically increased (as illustrated in Figures 6.2, 6.1, and 5) and learning outcomes could be measured. Learning achievement is predicted in TIE theory to be greatest under conditions illustrated in Figure 5 below, and least in Figure 6.2.

If these predictions are confirmed, TIE theory has highly significant implications for improving our current systems of education (which typically are more like Figure 6.2, when compared to Figure 5). These are nonobvious and unseen outcomes, and demonstrate the value of TIE theory (see Thompson, 2006b; Steiner, 1988).

In a similar vein, Einstein's Theory of Relativity predicted the bending of light from distant stars by the gravitational pull from large masses (e.g., such as our sun). This bending of light waves was a nonobvious, counterintuitive, and unseen event prior to Einstein's theory early in the 20th century. Einstein's theoretical prediction was nonetheless later empirically confirmed by new observations during a full solar eclipse. See Thompson (2006b).

While there are examples which implement parts of TIE theory (described in Section 3), I am unaware of any existing education system that is designed to maximize total integration as described in TIE theory. When researchers and practitioners refer to *systemic* change in education, TIE theory provides a foundation for predicting the effectiveness of newly designed education systems.

2. Introduction to TIE theory

When developing descriptive theory, we must have well-defined terms. Otherwise, theory lacks clarity. TIE theory makes clear distinctions between 12 kinds of learning—especially those kinds of learning that are within the domain of education and those that are not. See Figure 1.

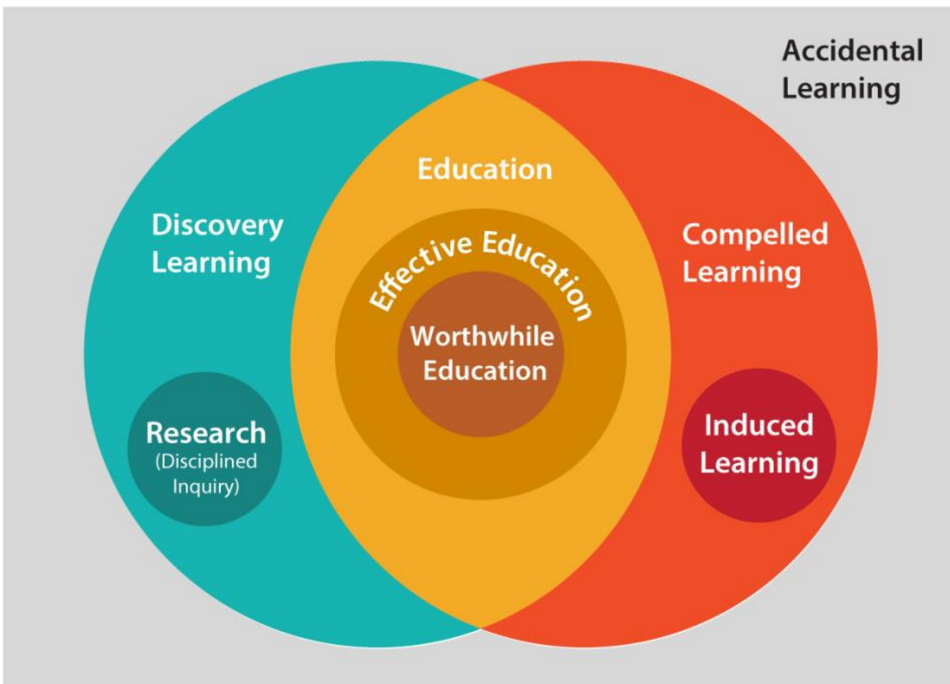

Figure 1. Venn diagram representation of kinds of learning and education (graphic design by Colin Gray and Ted Frick)

Twelve kinds of learning

First, education is not the same as learning. Education is a *subset* of all learning. Figure 1 illustrates the relationship between learning and education. Learning can occur without guidance—i.e., without teaching. To be education, however, learning must be both *guided* and *intended* (Steiner, 1988). Furthermore, not all education is effective or worthwhile. Some education can be ineffective. Some education can be effective but not worthwhile. Thus, these distinctions are made in the Venn diagram in Figure 1.

Key concepts from which definitions of types of learning are derived from this Venn diagram are further illustrated by specific shadings in Venn diagrams in Figures 1.1 – 1.13:

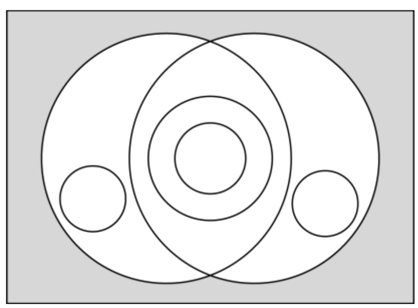

Figure 1.1. Accidental learning: neither intended nor guided (Type 1)

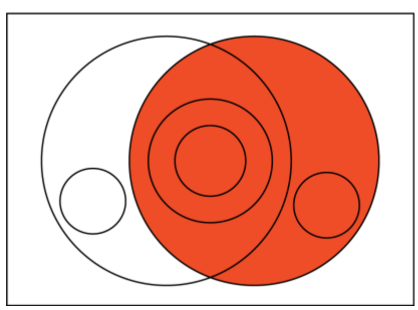

Figure 1.2. Guided learning (Type 2)

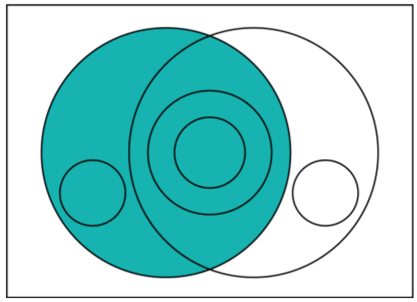

Figure 1.3. Intended learning (Type 3)

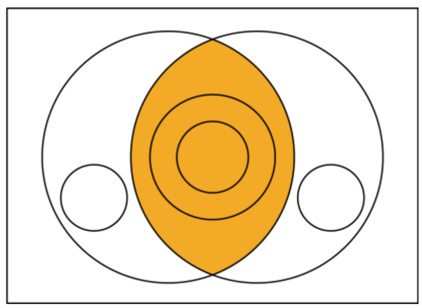

Figure 1.4. Conducive learning (education): Intended and guided (Type 4)

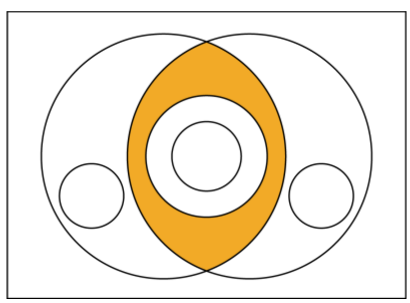

Figure 1.5. Ineffective education: neither instrumentally good nor intrinsically good (Type 5)

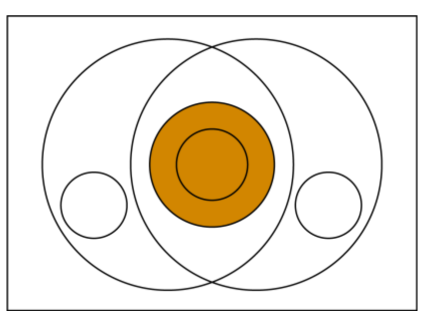

Figure 1.6. Effective education: instrumentally good (Type 6)

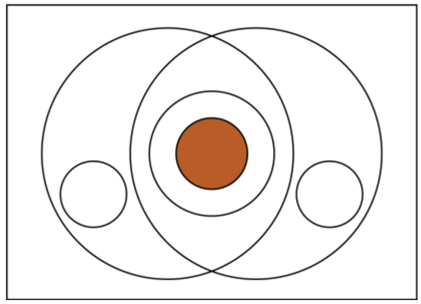

Figure 1.7. Worthwhile education: instrumentally and intrinsically good (Type 7)

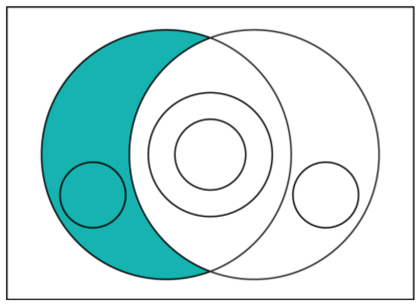

Figure 1.8. Discovery learning: intended but unguided (Type 8)

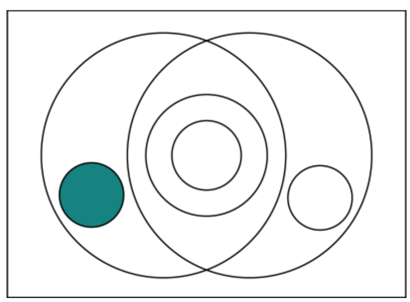

Figure 1.9. Disciplined inquiry (research): discovery learning that is regulated by criteria (Type 9)

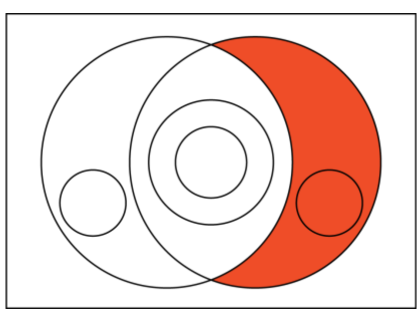

Figure 1.10. Compelled learning: guided but unintended (Type 10)

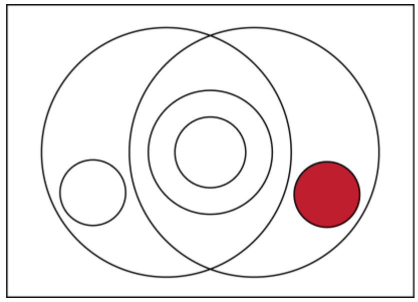

Figure 1.11. Induced learning: guided but initially-unintended (Type 11)

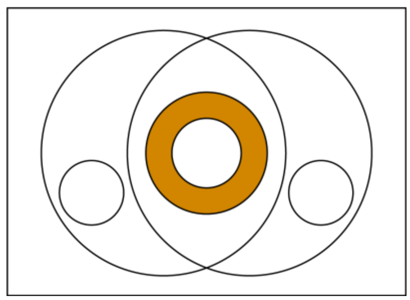

Figure 1.12. Effective bad education: instrumentally good but not intrinsically good (Type 12)

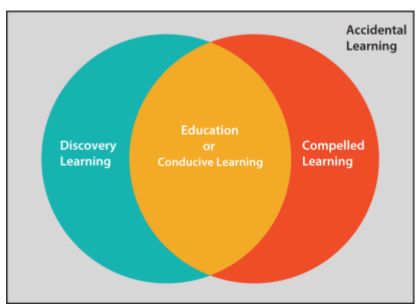

Figure 1.13. All learning: accidental or discovery or conducive or compelled

Basic predictions in TIE theory

The theory of totally integrated education (TIE) describes what is necessary for worthwhile education (Type 7 learning, Fig. 1.7). Learning is the formation of new mental structures. Complexity of the connectedness of structures increases. TIE theory further predicts that *mental structures will be strongest* when student willing, feeling and thinking are working in concert as she or he engages in learning tasks:

- *S* intends to learn *X*, and
- *S* feels strongly while learning *X*, and
- *S* forms new mental structures for *X* (i.e., *S* learns *X*)

where *X* is the integration of *knowing that*, *knowing how* and *knowing that one*, and *S* is the student.

Strongness is a systems structural property, as well as *integration* and *wholeness*. These properties of connectedness were described above, as well as in Axiomatic Theory of Intentional Systems (ATIS), developed by Thompson (2006a, 2008b). ATIS has further served as a *theory model* for development of TIE theory, and, in turn, set theory, di-graph theory, and general system theory have served as theory models for ATIS. Theory models are used in retroductive reasoning as part of new theory development (see Steiner, 1988; Thompson, 2006b, 2008b; Peirce, 1932). In contrast*, deductive reasoning* is used for creating logical implications derived from initial postulates and subsequent theorems. Finally, *inductive reasoning* is used for evaluating theorems and their deduced implications via empirical research in science and praxiology. See Steiner (1988), Peirce (1932), and Thompson (2006b).

According to Greenspan and Benderly (1997), the emotion arising through engagement in a learning task creates the architecture of the student's mental structure. This structure increases in complexity—there are more connections in a person's mental structure than before, which is the definition of learning in TIE theory. The dual coding of sensations and emotions from that experience *organize* the mental structure.

Figure 2 illustrates graphically the desired relationship among thinking, willing and feeling during the learning process. Cognition, intention and emotions are temporally connected, rather than being at odds with each other (disconnected). Ideally the learning task is something that the student intends to do, his or her thinking is focused on the learning task, and she or he feels strongly about this activity. From a biological perspective, synapses that connect neurons in long-term memory are chemically strengthened under these conditions. See Kandel (2001).

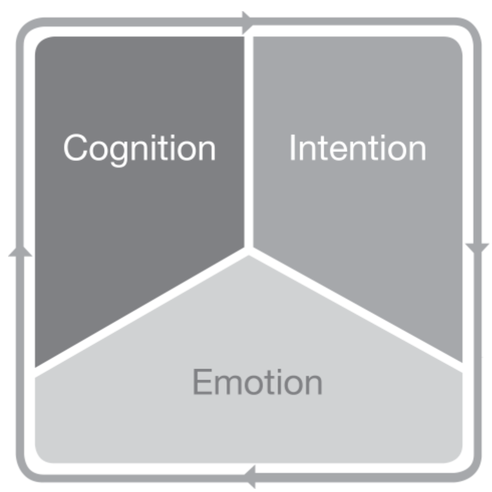

Figure 2. Schema for desired connections among a student's cognition (thinking), intention (willing), and emotion (feeling) during a learning activity (graphic by Colin Gray).

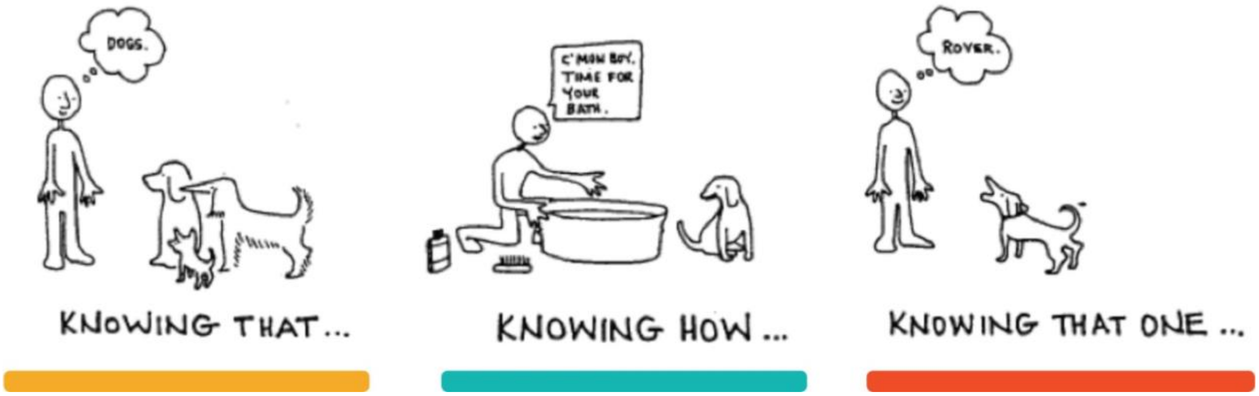

Figure 3. Illustration of three kinds of knowing (drawings by Elizabeth Boling).

The theory of totally integrated education (TIE) predicts that when three kinds of knowing are *integrated* (i.e., 'knowing that one', 'knowing how', and 'knowing that' are connected so as to remain whole), and when student cognition, intention and feelings are temporally connected, then students will form stronger mental structures. Strongly connected mental structures are less vulnerable to subsequent disconnection in long-term memory. Such structures are less vulnerable to forgetting.

For example, in Figure 3, the boy recognizes his unique dog, Rover ('knows that one'). He also 'knows that' Rover is an instance of the class of dogs, and he 'knows how' to give Rover a bath. A practical implication of TIE theory is that for education to be most effective, teachers should choose multiple learning tasks that result in student formation of strong connections among these kinds of knowing for each educational objective.

Furthermore, these learning tasks should be *authentic* (i.e., selected from the existing culture in which students and teachers live), so that students can see the relevance of the tasks to their personal lives. If students see the relevance and purpose of the tasks, then they are more likely to be motivated to engage in the learning tasks (Keller, 1983). In the Yazzie-Mintz (2007) study, students who were considering dropping out of school said, "I didn't see the value of the work I am expected to do" (p. 5). If educators design or choose learning tasks that are *authentic*, it will help students appreciate the value of those tasks. Appreciation is a type of qualitative knowing ('knowing that one').

Figures 4 and 5 illustrate further details and relationships among kinds of knowing. In particular, Figure 5 shows full integration of the 9 kinds of cognitive relations—they are completely connected, which is represented by the arrows between the rounded rectangles. From digraph theory and ATIS, *complete connectedness* is a system structural property. Furthermore, the embedding of the rounded rectangles illustrates the set-theoretical relationship within each kind of knowing. For example, appreciation is a subset of acquaintance and acquaintance is a subset of recognition. Both recognition and acquaintance are necessary (but not sufficient) for appreciation. Thus, if a learning task connects appreciation of 'that-one', creative 'know how', and criterial 'know that', then it follows via deductive reasoning that the 9 kinds of knowing must be connected since the other 6 are necessary for these three.

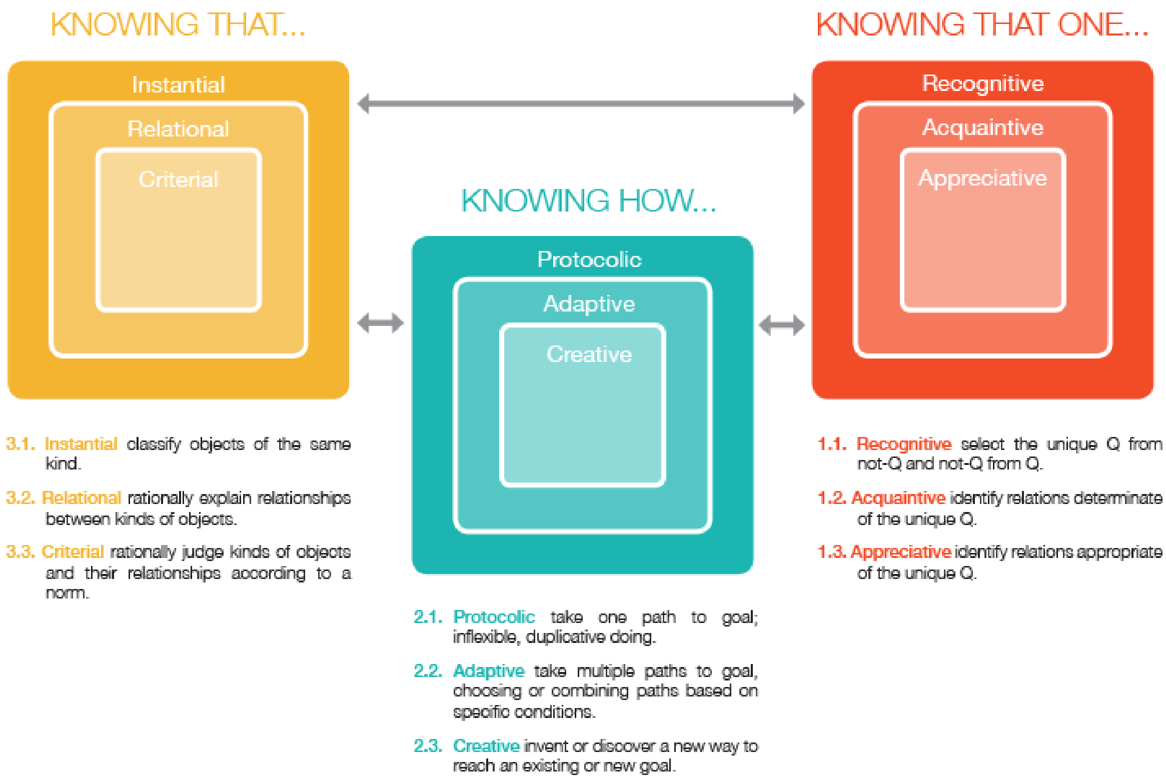

Figure 4. Further explication of kinds of knowing (graphic by Colin Gray).

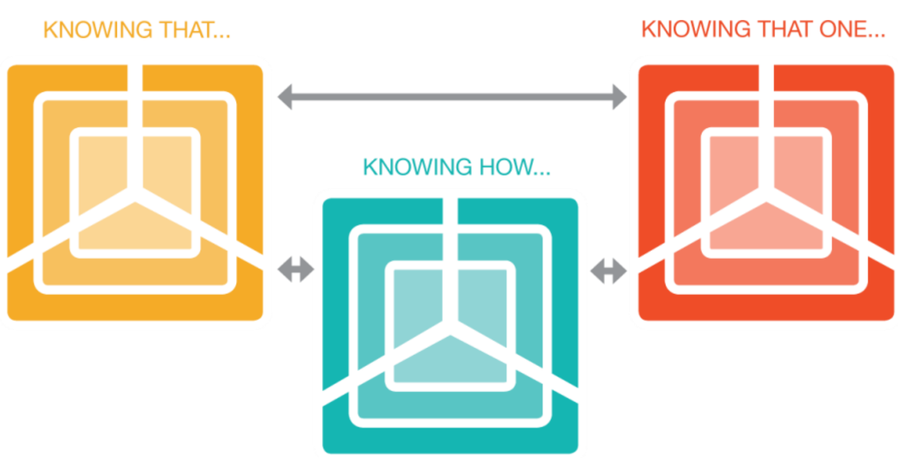

Figure 5. Illustration of completely-connected knowing where student cognition, intention and emotions are in harmony—i.e., Figure 2 is superimposed on Figure 4 to result in this figure (graphic by Colin Gray).

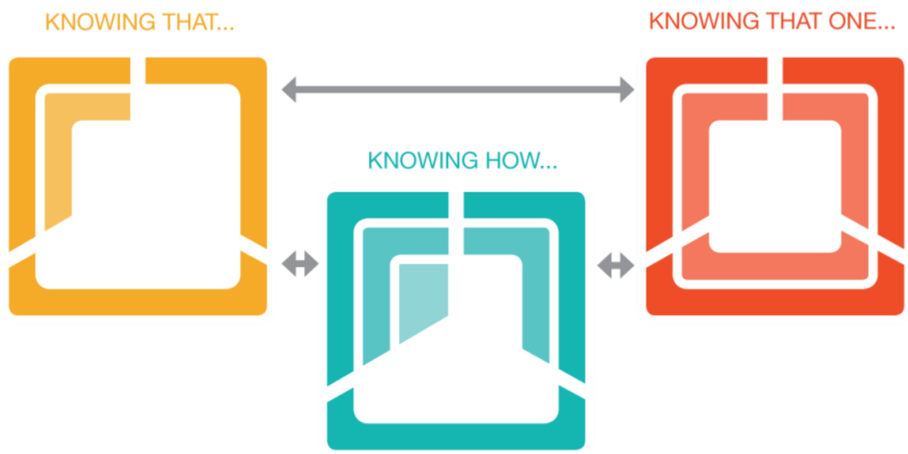

Figure 6.1. Illustration of partially-connected mental structures (graphic by Colin Gray). The lack of shading in the rounded rectangles represents absence of connectivity—hence cognition and thinking, willing and feeling are not totally integrated.

Figure 6.1 illustrates mental structures that are *not* completely connected. Note the gaps (white space, lack of shaded areas): Criterial relationships are missing with respect to cognition, intention and feeling. Relational (theoretical) connections are missing with respect to intention and feeling. Appreciative relationships are missing with respect to cognition, intention and feeling. Creative relationships are missing with respect to intention and feeling; and adaptive relationships are missing with respect to feeling.

Too often, the picture is even more empty—e.g., attempting to bring students to 'know that', without connecting 'knowing that' to 'knowing how' or 'knowing that one'. Furthermore, if students do not intend to learn (i.e., are compelled—Type 10 learning, Fig. 1.10), and their feelings are likewise out of sync (temporally disconnected), then what is illustrated in Figures 5 and 6.1 largely disappears. Such a graphic would be mostly empty, with very little to show (Figure 6.2). Under these conditions, TIE theory predicts that such disconnected learning—resulting in lack of *wholeness* of mental structures—will be highly vulnerable to forgetting.

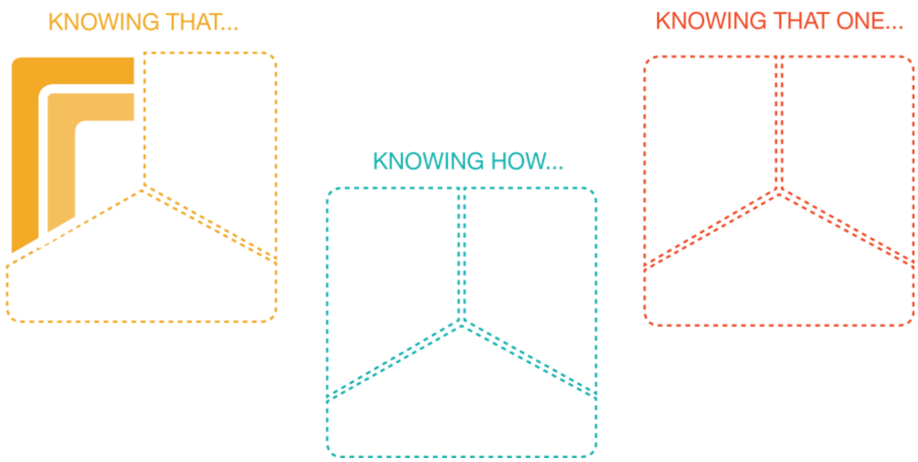

Figure 6.2. Disconnected mental structures (graphic by Colin Gray). 'Knowing how' and 'knowing that one' are disconnected from 'knowing that'. Student intention and emotion are disconnected from 'knowing that'.

This is the kind of disconnected learning that students often experience in school when they are bored. They are required to learn facts and concepts they do not care about, which have no perceived practical value, and which are disconnected from unique elements in their culture.

TIE theory contains numerous well-defined terms that constitute an important part of the descriptive theory. These defined and undefined terms are provided in Appendix A, not because they are unimportant—they are vitally important—but because they will likely make more sense to readers after some real-world examples, which are discussed next. These and other defined terms, many of which have examples that elaborate definitions, are available on the Educology website: https://educology.indiana.edu/.

3. Cases of two unique education systems that illustrate elements of TIE theory

SUNY Cobleskill

The State University of New York (SUNY) at Cobleskill has been recently implementing new cross-disciplinary programs that are attempting to integrate different kinds of subject matter and the three kinds of knowing that are part of TIE theory. Feldman (2016) describes new programs which include:

- Food Systems and Technology
- Fermentation Science and Applied Fermentation
- Graphic Design

In the Food Systems and Technology program, a student who had visited Puerto Rico, evidenced 'appreciative knowing that-one' who said:

> After meeting the workers and managers, seeing the terrain, and feeling the weather, I can now pick up a humble banana and marvel at the journey it took to reach the local grocery store. This is a view of the modern food system that the vast majority of American consumers will never get to see. (p. 3)

Feldman (2016) further writes:

> The program pulls together four academic cores—sustainability, food policy and law, food production and science, and food business management—to teach students how to efficiently and effectively produce, process and distribute food. The interdisciplinary

> approach also aims to instill the innovative mindset that will be needed to feed an ever-growing population…. Students in the program will get plenty of hands-on experience in the College's livestock and dairy facilities, greenhouses, alternative energy labs and culinary facilities. (p. 3)

This new program illustrates student learning activities that help make connected mental structures among 'knowing that', 'knowing how', and 'knowing that one' as described in TIE theory. In particular, the student visiting Puerto Rico has been learning about 'that one' and evidences 'appreciative knowing that one'. Furthermore, students in this program are getting hands-on experience, which illustrate connections between 'knowing how' and 'knowing that one' as they learn in the on-campus dairy facilities, greenhouses, etc. Through more traditional course work, students create mental structures for 'knowing that' and 'knowing how', for example, in "ag[riculture] business, culinary arts, animal science, plant science, ag engineering and more" (Feldman, 2016, p. 3).

The new program at SUNY Cobleskill on Fermentation Science and Applied Fermentation appears to be organized in a similar interdisciplinary approach:

> The programs are notable in their breadth, focusing on fermentation as it applies to fields like food and beverage production as well as pharmaceuticals, industrial manufacturing, environmental conservation, even renewable energy…. In using microbial processes to help turn waste into energy, the programs address sustainability and conservation; in growing fruits, vegetables or grains for a top-to-bottom farm brewery, they draw on agriculture; in producing foods like sauerkraut, kimchi, summer sausages, tea and coffee,

> they bring in the College's Culinary Arts program. They even include business courses, a rarity for fermentation programs. (Feldman, 2016, p. 5)

An old building on the SUNY Cobleskill campus was recently converted into a new Design Center,

> … a place where design and the visual arts all come together under one roof…. The centralization was driven by the introduction of a four-year Graphic Design program. On the second floor of the building today, art studios and gallery spaces have been carved out of what used to be a large gymnasium…. The labs offer easy, reliable access to the kind of technology students will encounter in the work environment…. The student design club, Logos, has experienced a revival, as well. Previously a place for students to share ideas and take design-related field trips, the club now functions as a student-run design agency for other clubs and community organizations. Club members design logos and flyers as well as offering other creative design solutions on a real-world commission model. (Feldman, 2016, pp. 8-9)

What is noteworthy with respect to TIE theory is that 'creative knowing how' and 'appreciative knowing that one' are interconnected through student learning in the Graphics Design program. Graphic Design students in the Logos club presumably are applying concepts and theories they have learned to their real-world projects, and are likely applying 'criterial knowing that' when evaluating and choosing design solutions during those projects with clients in the local community. Moreover, the connection of intentionality, emotion, and cognition are likely formed through these projects. See Figures, 2-5 in Section 2 above.

In effect, what appears to be happening at SUNY Cobleskill is the integration of three kinds of knowing as illustrated in Section 2, Figure 4 above. It is unclear from Feldman's description the extent to which student cognition, intention and emotion are interconnected (Figure 2). Nor is it clear if the new program is organized according to task-centered instruction—a series of whole, authentic tasks that are arranged from simple to complex. (See discussion in Section 4 below about *First Principles of Instruction* and the *4C/ID Model*).

I currently do not know whether or not faculty and administrators at SUNY Cobleskill have been explicitly aware of TIE theory and consciously applying its principles. Descriptions of this emerging TIE theory have been available on the Web since 2011. See:

- https://educology.iu.edu/Frick/index.html
- https://tedfrick.sitehost.iu.edu/research.html - major presentations.

In any case, it appears that recent new programs on SUNY Cobleskill campus illustrate practical implementations of TIE theory, as their faculty are creating new curriculum alongside more traditional courses and programs. It further appears that SUNY Cobleskill exemplifies the process of *systemic change* in education at the post-secondary level.

Bloomington Montessori School

The Bloomington Montessori School (BMS) began as a private preschool program in 1968 for 3- to 6-year-old children in Bloomington, Indiana. The BMS has grown to include elementary programs for students ages 6 to 9 and 9 to 12. Students in the BMS upper-elementary mixed-age program are similar in age to those in grades 4 through 6 in more traditional public schools. However, the Montessori approach is very different in ways in which student learning is structured, as well as in the curriculum resources, and how they are used to support student learning. Each classroom in the BMS is run by a head teacher certified by the American Montessori Society.

Koh and Frick (2010) conducted a case study of the BMS upper-elementary classroom, led by a male head teacher with 32 years of Montessori experience and two assistants, where 28 students were enrolled, ages 9 to 11 at the time of the study.

The classroom's physical appearance was notably different from a typical public school classroom in that the space was filled with rolling shelves containing "works" from the Montessori curriculum; stationary bookshelves containing a large number of books (not textbooks) for student use in doing research; science apparatus for conducting experiments; a few cages with birds and small animals, and some potted plants; and appropriately sized tables and chairs spread out in nooks and crannies (some with desktop computers on them). Separate boys' and girls' restrooms were immediately adjacent to the classroom. There was significant personal space in a further adjacent room for teachers to do preparatory work. The space, about the size of a large walk-in closet, contained private storage in cabinets and counter space for working. There was a further adjacent small observation booth with one-way glass windows for small groups of parents and visitors to observe the classroom (accessible only from a commons area outside the classroom). Most of the classroom was carpeted; many students would often do their work on the floor by using small mats to sit or lay on.

Compared with public school classrooms, there were abundant curriculum resources stored in the upper-elementary classroom itself that were immediately available to students.

There was also a massive attic area on the second floor above the classroom, where works were stored that were not in current use. Teachers would bring works into the classroom, depending on what students were learning at the time, and return works to the attic area that were no longer needed (typically when class was not in session). There was also a separate library nearby the upper-elementary classroom in the same building, where students could also work independently, and which contained not only books but also more desktop computers.

The BMS is incorporated as a non-profit organization run by a volunteer board, who are elected by parents of children who attend. It is a relatively autonomous private school, not under control by the state as is the public education system. The BMS school building that included new elementary programs was originally designed in the early 1980's through a cooperative endeavor among teachers and parents working with an architect and constructed by a local builder. New classrooms of similar configurations have been more recently added to the original building to handle growing demand and enrollments.

Central to the Montessori philosophy is that students are able to make their own individual *choices* about what to learn, when, and how long, in a carefully prepared and orderly environment which contains curriculum and hands-on materials readily available to students. For example, mathematics activities included works for arithmetic, fractions and decimals that are typical at the elementary school level, but also included works for more advanced students such as those covering set theory, algebra, and geometry—subjects typically learned at the high school level. There was a wide range of reading materials at various levels of reading difficulty. These books (not school textbooks) were relevant to student research projects and report writing—students did a large amount of research and writing activities in this upper-elementary class. Other works were available for geography with numerous maps and cultural information; and science works included apparatus for doing chemistry and physics experiments. Lillard (2008) has described many more aspects of the philosophy, methods, and curriculum resources that are part of Montessori's method. These are not discussed here due to space limitations.

With respect to organization of time at the BMS upper-elementary classroom Koh and Frick (2010) reported in their case study that the first hour of each day was typically spent doing "*Head Problems*" and the next three hours was the "*Morning Work Period*" before a break was taken for lunch. Each day the whole class would work on a *Head Problem* created by a teacher from current events or from other cultural artifacts in the community. For example, one of the *Head Problems* was: "A Sunkist soda contains X amount of caffeine. How many Hershey bars contain X amount of caffeine" (Koh and Frick, 2010, p. 9). Students not only needed to read and decode food nutrition labels on soda cans and candy bar wrappers, but also needed to understand measures of quantity such as ounces, grams, or milligrams, and convert measures from one to another. They may have needed to consult other resources in the process, and then use some basic algebra to answer the question. Each student was required to justify her or his conclusion by explaining how they arrived at facts and their reasoning process. Many *Head Problems* were based on local current events, and illustrated how mathematics could be practically used. Students worked at their own pace individually or in small groups as they tried to solve that morning's *Head Prob*lem. With respect to TIE theory, this *Head Problem* activity illustrated the connection of 'knowing that', 'knowing how', and 'knowing that one'. Unlike much of the rest of the day, all students in the class worked on the same *Head Problem* during the first 30-45 minutes of the day.

When a student finished the *Head Problem*, she or he individually moved on to their *Morning Work Period*, typically lasting about three hours. During this time interval *students chose individually* the Montessori *works* that they wanted to do. When finished with one *work*, they would return it to the shelf where they got it, and then would begin another *work*. What is notable is that, at any given time, a student was usually working on something *different* from what other students were doing in the classroom. Feedback was built into many works so students could judge themselves how well they were doing. Teachers were available to help students as needed, and to introduce new works to students when they were ready for it. But teachers tended to mostly be observing what students were doing and provided individualized student feedback as needed on the work each was attempting. Teacher-led, group-paced activities were seldom observed during the *Morning Work Period*.

Koh and Frick (2010) noted:

> Montessori education is established upon the philosophy of helping each child attain self-mastery and independence. It emphasizes that students be given autonomy to engage freely with their learning environment. This case study of an upper elementary classroom found that the Montessori philosophy of education guided how teachers used autonomy-supportive strategies. Teachers supported student organizational autonomy by allowing them choice in terms of school work and work partners. They fostered cognitive autonomy by encouraging student independent thinking, encouraging self-initiation, and honoring students' voice… Students surveyed [using the Academic Self-Regulation

> instrument] rated themselves highly in terms of intrinsic motivation for school work. (p. 1)

From the perspective of TIE theory, in this Montessori upper-elementary classroom student intention, emotion, and cognition were connected through learning activities they pursued, as illustrated in Figure 2 in Section 2. This contrasts with many traditional elementary schools where students have little choice of what to learn, when, and how long to spend on it. Teachers typically organize work periods by subjects (spelling, arithmetic, reading, science, etc.) which are group-paced and teacher-led—often based on a "Sage on the Stage" approach. This contrasts with typical Montessori classrooms, where teachers spend much of their time as "Guides on the Side."

From the perspective of TIE theory, what appeared to be often missing is directly connecting what students were learning in the Montessori classroom to unique elements in the local community and culture (at least as observed in the case study by Koh and Frick, 2010). It should be noted that in Montessori's curriculum beyond the upper-elementary level, students are expected to do more of their learning activities outside the classroom in their local communities (see A. Lillard, 2008; P. Lillard, 1996). The challenge, of course, in educating younger children is the need for adults to supervise and especially to address student safety concerns. Field trips into the local community setting provides logistical challenges that make such events relatively rare, when compared with the time spent in school classrooms during school hours. This contrasts with the mostly young adults who attend SUNY at Cobleskill, where more field work and learning is possible and is incorporated into their programs.

4. What is TIE theory good for?

New research studies

As mentioned in Section 1, the value of new theory is to predict unexpected, nonobvious, unseen and counterintuitive outcomes. Does TIE theory do that?

Empirical research studies can be designed which use Figures 1-6 as a basis of designing different kinds of learning environments. Learning achievement—particularly long-term achievement gains compared with short-term gains—can be investigated by manipulating components of TIE theory. For example, Figure 6.2 illustrates typical classroom learning in elementary, secondary, and postsecondary schools, where 'knowing that' is disconnected from 'knowing that one' and 'knowing how'. TIE theory predicts that, under these conditions, student mental structures will be weaker, more disconnected, and more vulnerable to forgetting, especially if relationships illustrated in Figure 2 are missing (i.e., lack of intention to learn, and lack of emotional involvement in learning activities).

On the other hand, Figure 5 illustrates completely-connected cognition, intention and emotion with 'knowing that', 'knowing how' and 'knowing that one'. These two kinds of contrasting systems (illustrated by Figures 5 and 6.2) could be empirically compared on a number of dimensions—student motivation and satisfaction, attitude towards learning, mastery of expected learning outcomes, teacher satisfaction, and so on. Modern technologies in neuroscience could also be used to study brain activity under various conditions of learning, as alluded to by Eagleman (2015).

TIE theory has further implications for schools without walls, that is, education systems which include local community and culture as integral parts of the education system as content for learning. This contrasts with exclusion of content about what happens outside classrooms in the local community. In other words, if students are learning in real-world contexts (i.e., literally through hands-on learning activities), would they be better able to connect 'knowing that' and 'knowing how' with authentic parts of their culture (with 'knowing that one')? After all, for tens of thousands of years humankind did learn in real-world contexts prior to more recent attempts via formal schooling in the 20th and 21st centuries where students have largely been sequestered inside buildings—e.g., see examples of alternatives in Frick (1991).

Designing new and improved curriculum for education

One implication of TIE theory is that extant curriculum for education can be significantly improved. For example, see Figures 6.1 and 6.2, which illustrate missing connections.

Traditional curriculum in P-16 schools has been carved up to the point that it is often difficult for students to see the relevance and value of learning activities in those subject areas, which is one of the primary reasons students are bored and unmotivated to learn (Yazzie-Mintz, 2007). Metaphorically speaking, Humpty Dumpty has been broken into many small pieces; the whole of Humpty Dumpty has been lost in traditional curriculum subjects such as algebra, geography, science, history, reading, writing, spelling, grammar and arithmetic.

A century ago Dewey (1916) also observed this problem in education:

> … the bonds which connect the subject matter of school study with the habits and ideals of the social group are disguised and covered up. The ties are so loosened that it often appears as if there were none; as if subject matter existed simply as knowledge on its own independent behoof… irrespective of any social values. (p. 181)

> The subject matter of the learner is not … identical with the formulated, the crystallized, and systematized subject matter of the adult…. [which] enters into the activities of the expert and the educator, not that of a beginner, the learner. Failure to bear in mind the difference in subject matter from the respective points of teacher and student is responsible for most of the mistakes made in the use of texts [books] and other expressions of preexistent knowledge. (pp. 182-183)

In TIE theory, the goal is to help learners create *mental structures that are whole* by attempting to completely connect the kinds of knowing with intention and emotion. Learning tasks which are authentic and whole are needed. The criterion of authenticity requires that the tasks should be selected from what people in the social system and culture actually do and which contribute to that social system. Students need to learn to participate in that social system and to be productive members of society, contributing to overall well-being of the social system. The primary goal of education should be the transmission of good culture, and that this has been vital to the advancement of human civilization and good culture.

Dewey (1916) recommended the same approach as I now do in TIE theory: engage students in meaningful learning through direct hands-on experience. Dewey started a laboratory school at the University of Chicago, which still exists, in order to test his ideas. Although his notion of progressive education never caught on in mainstream education, more recent educational approaches such as *Ten Steps to Complex Learning* (van Merriënboer & Kirschner, 2013) and *First Principles of Instruction* (Merrill, 2013) are consistent with fundamental ideas that Dewey originally promoted, and provide clear elaborations of important ideas.

Task-centered instruction

While it is useful to have current examples of meaningful education, the point here is not to advocate particular approaches such as the Bloomington Montessori School or SUNY Cobleskill as the answer to education's problems. Rather, the goal is to use the principles from TIE theory to design and develop curriculum and instruction organized by authentic tasks.

Noteworthy is that Merrill, Barclay and van Schaak (2008) have articulated the difference between task-centered instruction and topic-centered instruction. For a specific example, see the report by Mendenhall, et al. (2006). The same goals of topic-centered instruction (subject matter to be learned) can be achieved by task-centered instruction.

A significant challenge is to design and sequence such authentic whole tasks without generating student cognitive overload. Too much cognitive load will interfere with learning (see van Merriënboer, Kirschner & Kester, 2003). One instructional design approach shows promise in how to sequence tasks for complex learning while managing student cognitive load: the Four-Component Instructional Design (4C/ID) model, further explicated by *Ten Steps to Complex Learning* (van Merriënboer & Kirschner, 2013). They recommend that instructional designers begin by identifying an authentic, whole, real-world task as the goal. Since such a complex task would be overwhelming for a novice, the essential relationships of the whole task are identified, so that versions of the whole task can be arranged from simple to complex. Each version of the whole task is called a task class. Within each task class, variations of the task are created, along with supportive information, just-in-time procedural information, and part-task practice (if needed). As the learner completes variations of the whole task in the task class, the amount of support (e.g., teacher feedback, coaching, scaffolding) is gradually faded until the student can perform the entire task independently. Then the student moves to the next task class, which is a little more complex, and the whole cycle is repeated. Students proceed through task classes in this manner until they can successfully perform the original authentic, whole, and complex task that was identified as the goal.

What is noteworthy about Dewey's philosophy, Bloomington Montessori School, SUNY Cobleskill, and the *Ten-Steps-to-Complex-Learning* model is that students are expected to engage in authentic, purposeful tasks or projects. Education can be organized by these tasks/projects, rather than by traditional subjects, and the levels of complexity of these tasks can be matched to what students are capable of doing at their current level of development.

The same educational goals can be achieved with respect to traditional curriculum standards, but the means of accomplishing these goals would be different.

When instruction and learning activities are grounded in authentic tasks, a further benefit is that students will come to 'know that one' in the process of learning. As Estep (2006) observed, tasks for 'knowing how' are grounded in particulars—i.e., such authentic tasks are performed in a unique context. Furthermore, many kinds of 'knowing how' benefit from 'knowing that'. In other words, students can apply generalizable concepts, relations and criteria as they carry out a specific task. Performance of these tasks can help students connect their mental structures for 'know how' with 'know that one' and 'know that'. Mental structures are literally TIE'd together.

Summary of the theory of Totally Integrated Education

Totally integrated education results in completely–connected student *knowing*. Completely-connected knowing results in holistic student mental structures. That is, students should form interconnected mental structures for:

- *knowing that one* (right opinions: recognizing, becoming acquainted with, and appreciating authentic uniques in one's culture),
- *knowing how to do* (effective and ethical action: protocolic, adaptive, and creative conduct), and
- *knowing that* (true beliefs: understanding concepts, explicating theories, and applying rational criteria for judgment).

Students are expected to form mental structures for *right* opinions, *effective and ethical* doings, and *true* beliefs—that is, the goal should be *worthwhile* education. Students should *not* form mental structures for *wrong* opinions, for *ineffective or unethical* doings, or for *false* beliefs.

When teachers select or create learning activities that help students to appreciate unique elements of their culture, to be creative in their doings, and to rationally judge kinds of objects and their relationships according to norms, then students are predicted to form more completely-connected mental structures, as illustrated in Figures 4 and 5. Such strong mental structures are predicted to be less vulnerable to forgetting. When emotion, intention, and thinking are temporally connected through learning tasks in which students are engaged, mental structures are more likely to be strengthened (see Section 2, Figures 2, 3, 4, and 5). For further explication of these ideas, and in particular a glossary of terms used in TIE theory, see the Educology website: http://educology.indiana.edu/index.html.

The acronym, TIE, expresses that the central idea is literally to *tie together ideas in our minds through interconnected mental structures formed through intentional, emotional, and cognitive experiences*.

5. References

Brandes, U. & Erlebach, T, (Eds.) (2005). *Network analysis: Methodological foundations*. Heidelberg, Germany: Springer-Verlag.

Dewey, J. (1916). *Democracy and education*. New York, NY: The Free Press.

Eagleman, D. (2015). *The brain*. New York, NY: Pantheon Books.

Educology (2016). *Knowledge of education*. Retrieved January 27, 2017 from: https://educology.iu.edu/

Estep, M. (2006). *Self-organizing natural intelligence: Issues of knowing, meaning and complexity.* Dordrecht, The Netherlands: Springer.

Feldman, J. (Ed.) (Autumn 2016). *SUNY Cobleskill magazine*. Albany, NY: Fort Orange Press.

Frick, T. W. (1991). *Restructuring education through technology*. Bloomington, IN: Phi Delta Kappa Education Foundation.

Frick, T. W. (1997). Artificially intelligent tutoring systems: What computers can and can't know. *Journal of Educational Computing Research, 16*(2), 107-124.

Greenspan, S. I. & Benderly, B. L. (1997). *The growth of the mind and the endangered origins of intelligence.* Reading, MA: Addison-Wesley.

Greenspan, S. I. & Shanker, S. G. (2004). *The first idea: How symbols, language, and intelligence evolved from our primate ancestors to modern humans.* Cambridge, MA: Da Capo Press (Kindle edition).

Kandel, E. R. (1989). Genes, nerve cells, and the remembrance of things past. *Journal of Neuropsychiatry, 1*(2), 103-125.

Kandel, E. R. (2001). The molecular biology of memory storage: A dialogue between genes and synapses. *Science, 294,* 1030-1038.

Keller, J. M. (1983). Motivational design of instruction. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: An overview of their current status* (pp. 383-434). Mahwah, NJ: Lawrence Erlbaum Associates.

Koh, J. & Frick, T. (2010). Implementing autonomy support: Insights from a Montessori classroom. *International Journal of Education, 2*(2:E3), 1-15.

Lillard, A. S. (2008). *Montessori: The science behind the genius.* New York: Oxford University Press.

Lillard, P. P. (1996). *Montessori today: A comprehensive approach to education from birth to adulthood*. New York, NY: Schocken Books.

Maccia, G. S. (1986). Right opinion and Peirce's theory of signs. Paper presented at the Semiotic Studies Faculty Seminar. Retrieved January, 27, 2017 from: https://educology.iu.edu/Maccia/RightOpinionAndPeircesTheoryOfSigns_GSMaccia1987.pdf

Maccia, G. S. (1987). Genetic epistemology of intelligent natural systems. *Systems Research, 4*(3), 213-218. Retrieved January, 27, 2017 from: https://educology.iu.edu/Maccia/Correspondence_GeneticEpistemologyOfIntelligentNaturalSystems1987.pdf

Maccia, G. S. (1988). Genetic epistemology of intelligent natural systems: Propositional, procedural and performative intelligence. Paper presented at Hangzhou University, China. Retrieved January, 27, 2017 from:

https://educology.iu.edu/Maccia/GeneticEpistemologyOfIntelligentSystems_propositionalProceduralPerformativeIntelligence1988.pdf

Merrill, M. D., Barclay, M., & van Schaak, A. (2008). Prescriptive principles for instructional design. In J. M. Spector, M. D. Merrill, J. van Merriënboer, & M. F. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 173–184). New York: Lawrence Erlbaum Associates.

Mendenhall, A., Buhanan, C. W., Suhaka, M., Mills, G., Gibson, G. V., & Merrill, M. D. (2006). A task-centered approach to entrepreneurship. *Tech Trends, 50*(4), 84-89.

Peirce, C. S. (1932). *Collected papers, Vol. II, Elements of logic* (C. Hartshorne & P. Weiss, Eds.). Cambridge, MA: Harvard University Press.

Peirce, C. S. (1934). *Collected papers, Vol. V, Pragmatism and pragmaticism* (C. Hartshorne & P. Weiss, Eds.). Cambridge, MA: Harvard University Press.

Squire, L. R. & Kandel, E. R. (1999). *Memory: From mind to molecules.* New York, NY: Henry Holt and Co.

Steiner, E. (1988). *Methodology of theory building.* Sydney: Educology Research Associates.

Thompson, K. R. (2006a). "General system" defined for predictive technologies of A-GSBT (Axiomatic General Systems Behavioral Theory). *Scientific Inquiry Journal, 7*(1), 1-11.

Thompson, K. R. (2006b). Axiomatic theories of intentional systems: Methodology of theory construction. *Scientific Inquiry Journal, 7*(1), 13-24.

Thompson, K. R. (2008a). ATIS glossary. Retrieved January, 27, 2017 from https://aptac.sitehost.iu.edu/glossary/

Thompson, K. R. (2008b). *ATIS graph theory*. Columbus, OH: Systems Predictive Technologies. Retrieved January, 27, 2017 from: https://aptfrick.sitehost.iu.edu/overview/reports/11ATISgraphtheory.pdf

van Merriënboer, J. J., Kirschner, P.A., & Kester, L. (2003). Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psychologist, 38*(1), 5-13.

van Merriënboer, J. J. & Kirschner, P.A. (2013). *Ten steps to complex learning: A systematic approach to four-component instructional design.* New York, NY: Routledge.

Yazzie-Mintz, , E. (2007). Voices of students on engagement: A report on the 2006 high school survey of student engagement. Retrieved January, 27, 2017 from http://www.eric.ed.gov/PDFS/ED495758.pdf

6. Appendix A: Defined and undefined terms in TIE theory

Definitions of basic terms in TIE theory

In order to explicate theory, it is necessary to define terms. Steiner (1988) states it this way:

> … when one sets forth the terms of the theory and their definitions, descriptive metaphysics is presented…. Descriptive metaphysics is a division of the phenomena which are the object of theorizing—the system—so that a set of descriptors characterizing the system's properties emerges. To do this, the metaphysician must provide a set of class terms for characterizing each and every component of the system…. Therefore, classification is basic to descriptive metaphysics.
>
> However, classification always involves definition. A class term denotes all the particulars to which the term is applicable (the extension of the term) and connotes the characteristics that a particular must have in order for the term to be applicable to it (the intension of the term). (Steiner, 1988, p. 64)

Steiner provides criteria for evaluating descriptive theory: exactness, exclusivity, exhaustiveness, external coherence, extendibility, equivalence, chaining and substitution (pp. 64-74). Descriptive theory is necessary for building a foundation before explanatory theory can be explicated.

Fundamental to TIE theory are the following defined terms ('$=_{Df}$' is read as 'is defined as')[2]:

- *Mental structures* $=_{Df}$ affect-relations[3] which constitute intelligence[4]
- *Learning* $=_{Df}$ increasing of complexity of a person's mental structure (for Types 1 – 12)
- *Learner* $=_{Df}$ person whose volition is learning
- *Forgetting* $=_{Df}$ decreasing of complexity of a person's mental structure

I have been discussing 'mental structure' above, and now I must be more precise. I take some definitions here from general system theory, and in particular, Axiomatic Theories of Intentional Systems (Thompson, 2006a, b; 2008a, b). 'Affect-relations' are the connections among components of a system, and 'complexity' is the number of connections. Thus, learning is defined as *increasing* the number of connections in a one's mental structure. This is consistent with what Kandel (1989) has concluded on a biological level, claiming that long-term memory is "associated with growth in synaptic connections [among neurons]" (p. 115), and that "learning produces enduring changes in structure and function of synapses" (p. 121).

The biological explanation of changes in the human nervous system is not part of TIE theory. TIE theory asserts that humans form mental structures as they learn. To use

[2] These and other terms are defined at https://educology.iu.edu/. This website provides definitions of these terms and more. It is easier to follow the chains of definitions on the website by clicking on the hyperlinks.

[3] Words which are red colored are defined elsewhere by Thompson (2008). See https://aptac.sitehost.iu.edu/glossary/. These terms, defined in Axiomatic Theories of Intentional Systems (ATIS) can also be viewed at https://educology.iu.edu/.

[4] Mental structures can be formed for right and wrong opinions, for effective, ineffective, ethical, and unethical conduct, and for true or false beliefs.

Steiner's criterion, there is external coherence. This definition of learning in TIE theory has external coherence with biological knowledge.

Undefined terms

Some terms in a theory must remain undefined (Steiner, 1988). Definitions could go on *ad infinitum* if there are no primitive terms. This is to avoid circularity in definitions, as well as infinite regress. Undefined terms in TIE theory follow: *intelligence, think, feel, intend, believe, perceive, guide, person, good, object (thing), course of action (conduct), end (goal).*

More definitions of terms in TIE theory

The domain of human learning is shown as a Venn diagram in Figure 1, which illustrates defined terms that include 'intended learning', 'guided learning', 'education', 'effective education' and 'worthwhile education'. Figures 1.1 through 1.13 illustrate via shadings in the Venn diagram how these terms are related but yet distinct.

- *Accidental learning* $=_{Df}$ learning which is neither guided nor intended (see Figure 1.1)
- *Discovery learning* $=_{Df}$ learning which is intended but unguided (see Figure 1.8)
- *Compelled learning* $=_{Df}$ learning which is not intended but guided (see Figure 1.10)
- *Conducive learning* $=_{Df}$ *education* $=_{Df}$ learning which is both intended and guided (see Figure 1.4)
- *Student* $=_{Df}$ a person who intends to learn content with a teacher
- *Teacher* $=_{Df}$ a person who intends to guide another person's learning

- *Teaching* $=_{\mathrm{Df}}$ a teacher guiding another person's learning (see Figure 1.2)
- *Sign* $=_{\mathrm{Df}}$ *representamen* $=_{\mathrm{Df}}$ "something which stands to somebody for something in some respect or capacity…. every representamen being thus connected with three things, the ground, the object, and the interpretant" (see Peirce, 1932, 2.228)
    - Interpretant $=_{\mathrm{Df}}$ a sign derived by a person as a mental construct that is a representamen of the equivalent external sign, which relates to an object
- *Content* $=_{\mathrm{Df}}$ objects and signs of objects selected for student learning
- *Context* $=_{\mathrm{Df}}$ system environment of teacher and student that contains content
- *Education system* $=_{\mathrm{Df}}$ intentional system consisting of at least one teacher and one student in a context
- *Knowing* $=_{\mathrm{Df}}$ mental structures which consist of warranted beliefs[5], right opinions, and capabilities for performance (See Figures 2, 3 and 4)[6]
    - '*Knowing that one*': mental structures for right opinion
        - *Recognitive*: select the unique *Q*[7] from not-*Q* and not-*Q* from *Q.*
        - *Acquaintive*: identify relations determinate of the unique *Q.*
        - *Appreciative*: identify relations appropriate of the unique *Q.*

[5] C. S. Peirce (1877) discussed four methods of fixating belief: tenacity, authority, agreeableness to reason, and science. Scientific method (or more generally disciplined inquiry) means that any rational agent can repeat the same method and should come to the same conclusion.

[6] Other mental structures can result from learning, such as beliefs that are unwarranted by the method of science, such as authority or agreeableness to reason. Learning can also create mental structures for wrong opinion, and for ineffective and unethical conduct.

[7] Q is the unique object of knowing.

- ‘*Knowing how*’: mental structures for effective performance
    - *Protocolic*: take one path to goal.
    - *Adaptive*: take alternative paths to goal, choosing or combining paths based on specific conditions.
    - *Creative*: innovate or invent a new way to reach an existing or new goal.
- ‘*Knowing that*’: mental structures for beliefs warranted by disciplined inquiry
    - *Instantial*: classification of objects of the same kind.
    - *Relational*: rational explanation of relationships between kinds of objects.
    - *Criterial*: rational judgment of kinds of objects and their relations according to a norm.

- *Knowledge* $=_{Df}$ record of knowing $=_{Df}$ preservation of signs that represent what is known in some medium external to knower
- *Disciplined inquiry* $=_{Df}$ rigorous research $=_{Df}$ learning which is regulated by criteria for creating scientific, praxiological, and philosophical knowledge.[8] (See Figure 1.9.)

[8] Of course, persons who are called teachers can work together with students in disciplined inquiry. In this case they are both intending to learn something that is unknown to either. In this sense, the teacher is not acting as a guide because he or she does not know their destination. Rather they are exploring together—attempting and intending to learn something new. The process of disciplined inquiry is regulated by criteria. This is different from when a teacher is leading a student to a known outcome, such as repeating an experiment that has already been done—e.g., by dropping a feather and a golf ball in a vacuum, to “discover” that their acceleration is the same. The student might learn something new in this case, but not the teacher. Isaac Newton did not have a teacher to lead him to discover the laws of gravity. Rather, he did this through disciplined inquiry.

- *Instrumentally good* $=_{Df}$ means that are good for an end (goal)
    - *Means* $=_{Df}$ course of action, a way to reach an end (goal)
- *Intrinsically good* $=_{Df}$ means or ends that are good in themselves, not with respect to their instrumental goodness
- *Effective Education* $=_{Df}$ education that is instrumentally good (Steiner, 1988, pp. 16-17) (See Figure 1.5.)
- *Effective Bad Education* $=_{Df}$ education that is instrumentally good but not intrinsically good (See Figure 1.12.)
- *Worthwhile Education* $=_{Df}$ education that is both instrumentally and intrinsically good (Steiner, 1988, p. 17) (See Figure 1.7.)
- *Totally Integrated Education* $=_{Df}$ education that results in student completely-connected knowing, intention and feeling (See Figure 5.)