Measuring System Structural Properties of Autonomy-Support in a Montessori Classroom

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Purpose

This qualitative case study analyzes classroom structures that supported student autonomy in a Montessori classroom. Using the Axiomatic Theories of Intentional Systems (ATIS) as a theoretical model, it also explores how a logico-mathematical general system model can be used to characterize the configurations underlying classroom interaction.

Montessori classrooms and autonomy-support

Deci, Vallerand, Pelletier & Ryan (1991) defined autonomy or self-determination as a state where one's volition was totally internalized and unaffected by external conditions. Surveys of school-age children found that students perceived teachers to be highly autonomy- supportive when they gave choice, had confidence in their ability, respected, and empathized with them (Hardre & Reeve, 2003). Autonomy-supportive social contexts were also found to have positive effects on children's interest for learning, level of conceptual learning, and willingness to perform uninteresting activities (Grolnick & Ryan, 1987; Joussemet, Koestner, Lekes, & Houlfort, 2004).

Montessori schools exhibit the characteristics of autonomy-support as described by the preceding studies. Its founder, Dr Maria Montessori, believed that education should help each child become a disciplined individual who is "master of himself, and can, therefore, regulate his own conduct when it shall be necessary to follow some rule of life." (Montessori, 1964, p. 86). It is also undertaken with a scientific approach where children were treated as natural phenomenon to be observed and understood. Teachers prepare the classroom with *Works* or instructional activities, and allow students choice to engage in what interests them (Cossentino, 2006). Teachers then make observations, and modify the *Works* to maintain students' learning engagement, and to stimulate interest in the *Works* they do not naturally choose. Even though children were given liberty to manifest themselves naturally, Montessori believed that they should be disciplined when they cause disruptions to learning.

When the social context of Montessori and traditional middle schools were compared, Rathunde and Csikszentmihalyi (2005) found that Montessori students reported more support from teachers; more order in the classroom, and a greater feeling of emotional/psychological safety. They also spent more time with academic work, group work, collaborative learning, and individual projects; but less time in passive listening via lecturing and note-taking. The authors concluded that analysis of school contexts that fostered intrinsic motivation could provide concrete ideas for improving student engagement in public schools.

Logico-mathematical General System Theory models

General systems theory (GST) postulated that systems could have common characteristics and behavior regardless of whether these were scientific, natural or social (von Bertalanffy, 1968). Mathematical models were used as an "exact language permitting rigorous deductions and confirmation (or refusal) of theory" (von Bertalanffy, 1972, p.30). Maccia and Maccia (1966)'s SIGGS theory model was developed specifically for educational theorizing. Thompson (2005a; 2005b; 2005c; 2006; 2007) formulated the Axiomatic Theories of Intentional Systems (ATIS) by improving on the consistency of SIGGS nomenclature, and converting SIGGS hypotheses into a set of axioms or assumptions underlying general systems behavior. ATIS basic properties describe system characteristics such as the number of system components (*size*), and the number of *affect relations* or connections between system components (c*omplexity*). Structural properties characterize the configuration of an *affect relation* set, while dynamic properties describe event changes that occur within a system, or its transactions with the *negasystem* (environment outside system boundaries).

Cossentino (2005) found Montessori classrooms to be characterized by discernable rituals that teachers use. Using the ATIS theory model, this study attempted to describe these rituals by measuring nine general system properties from the interactions between teachers and students, and triangulating these with qualitative and survey data to determine the structural configurations that support student autonomy in a Montessori classroom.

Method

Subjects

The study was conducted in an upper elementary (fourth to sixth grade) classroom of a Montessori school located in the state of Indiana. It consisted of 28 students, ranging from 9 to 11 years old, a Montessori-certified head teacher, and two assistant teachers.

Classroom context

In each 16-week session, students completed mandatory number of *Works* which include research projects; book reports; workbooks in Math and flash card drills. Teachers made a punch on individual cards that tracked their progress when an item of their required *Works* was completed. A typical day in the school was from 8:30 a.m. to 3:30 p.m. The morning started with students working on a *Head Problems* worksheet that consisted of math and logic-related problems designed by teachers. When this was completed, students moved into the *Morning Work Period* where they were free to work individually or collaboratively on their *Works*. About half an hour before recess at noon, students re-gathered to present their answers for the *Head Problems*. After lunch at 1 p.m., students attended Spanish or History classes and would end the day with cleanup duties at about 3 p.m.

Procedure

This study was first approved by the School Board of the Bloomington Montessori Association, following which consent forms for study participation were circulated to parents; where consent was obtained for 10 students. Ten one-hour observations were then conducted in the classroom during April 2006 where two to three observations were made each week. Each observation lasted about an hour, usually between 8:30 a.m. to 9:45 a.m. This time segment was chosen upon consultation with teachers as they felt that the classroom activities best reflected how the major portion of students' learning goals were completed in a mixed-grade Montessori classroom.

Montessori classrooms emphasized children's freedom to move around and work where they felt most comfortable. Even though the use of video equipment would have afforded greater precision for data collection, it was not possible to film only those subjects with parental consent without disrupting the normal operations of the classroom. Therefore, ethnographic field-notes were used to record the various types of interactions occurring between teachers and students. Cossentino (2006) employed the same data collection strategy in an effort to respect its classroom norms when studying work patterns in a Montessori classroom.

To determine if the motivational style of teachers is associated with their teaching method, the *Problems in Schools Questionnaire* (SDT Website, 2006a) was administered to each teacher at the beginning of the study. The purpose of the questionnaire and their results were not revealed until the end of observations Teachers rated 32 motivational strategies on a Likert scale of 1 (very inappropriate) to 7 (very appropriate). A one-hour semi-structured focus-group interview was also conducted with them at the end of the observations.

Students' level of intrinsic motivation for doing schoolwork was assessed through the *Academic Self-Regulation Questionnaire* (SDT Website, 2006b). This was administered only to the students with parental consent both at the beginning and end of the observations so that consistency of ratings could be verified. It consisted of 32 questions that measured four types of motivations for doing schoolwork. Each question was scored on a Likert Scale of 1 (Not at all true) to 4 (Very true).

Data analysis

Categorizing classroom interactions

The constant comparative method (Creswell, 1998) was used to derive 43 common interactions that occurred between teachers, students, and learning resources. These were further grouped into three categories (affect relations): *Instructional*, *Support,* and *Control*. The interactions and their proposed categories were verified with the teachers through an interview.

Measuring system properties

Interactions underlying each affect relation was identified by matching of frequency and pattern occurrences (Yin, 2003), and then described as ordered pairs that characterize the direction of connections between components. It is a notational system used by the Set and Diagraph theories which underlie ATIS. The nine system properties for each type of affect relation (Thompson, 2006) were measured as follows:

1. Size: The number of components in a system.

Size, $\mathcal{Z}(\mathfrak{S})$, $=_{df}$ components of an object-set.

$$\mathcal{Z}(\mathfrak{S}) =_{df} \mathcal{W} \subset \mathfrak{S}_0$$

2. Complexity: The total number of connections occurring between components in a system.

Complexity-component partition, ${}_{\mathcal{X}}\mathfrak{S}$, $=_{df}$ a *partition*, $\mathcal{Y} = (\mathcal{V} \subset \mathcal{G}_0, \mathcal{R} \subset \mathcal{G}_{\mathcal{A}})$, characterized by the number of affect-relations.

$${}_{\mathcal{X}}\mathfrak{S} =_{df} |\mathcal{Y}(\mathcal{R})|$$

3. Passive Dependence: The extent to which system components are receiving connections. It is computed by first tabulating the number of connections received by each component, and then taking their product.

$\mathcal{M}$: **Passive dependent-component partition measure,** $\mathcal{M}({}_{PD}\mathfrak{S})$, $=_{df}$ a measure of receiving component affect-relations.

$$\mathcal{M}({}_{AD}\mathfrak{S}) =_{df} [(\Sigma_{i=1,\ldots,n}[\Pi d_{\mathcal{T}}(v) \div \log_2|\mathcal{A}_i|]) \div n] \times 100$$

4. Interdependence: The extent to which components initiate and receive connections. It is computed by first identifying components that both initiate and receive connections. Then, the product of total paths initiated and received by these components is computed.

$\mathcal{M}$: **Interdependent system measure,** ${}_{N}\mathfrak{S}$, $=_{df}$ a measure of initiating and receiving associated component affect-relations.

$$\mathcal{M}({}_{N}\mathfrak{S}) =_{df} [(\Sigma_{i=1,\ldots,n}[\log_2 \Pi d|\gamma_{d(\mathcal{I},\mathcal{T})}(e) = 1|) \div \log_2|\mathcal{A}_i|]) \div n] \times 100$$

5. Strongness: The extent to which system components are connected. It is measured by the product of total connections received and initiated by each component.

$\mathcal{M}$: **Strong-component partition measure,** ${}_{S}\mathfrak{S}$, $=_{df}$ a measure of the degree of connected components.

$$\mathcal{M}({}_{S}\mathfrak{S}) =_{df} [(\Sigma_{i=1,\ldots,n}[\log_2 \Pi d(v) \div \log_2|\mathcal{A}_i|]) \div n] \times 100$$

6. Centrality: The extent to which primary-initiating components have indirect control. It is computed by the total path length of connections from primary-initiating components that have a path length greater than 1 and comparing it $|A_i|$. Primary-initiating components are those that only initiate and do not receive connections.

$\mathcal{M}$: **Centralized-component partition measure,** $\mathcal{M}({}_{C}\mathfrak{S})$, $=_{df}$ a measure of primary-initiating, non-adjacent component affect-relations.

$$\mathcal{M}({}_{C}\mathfrak{S}) =_{df} [(\Sigma_{i=1,\ldots,n}[|\gamma_{d(\mathcal{I}\mathfrak{S})}(e) > 1|) \div \log_2|\mathcal{A}_i|]) \div n] \times 100$$

7. Complete Connectivity: The extent to which system components are able to connect to other components either directly or indirectly. This is computed by the sum of completely connected paths occurring in the system.

$\mathcal{M}$: **Complete-component partition measure,** $\mathcal{M}({}_{CC}\mathfrak{S})$, $=_{df}$ a measure of pair-wise directed associated component affect-relations.

$$\mathcal{M}({}_{CC}\mathfrak{S}) =_{df} [(\Sigma_{i=1,\ldots,n}[|\gamma_d(e) \geq 1|) \div \log_2|\mathcal{A}_i|]) \div n] \times 100$$

8. Hierarchical Orderness: The extent of the occurrence of a *tree*. A tree is an acyclic simple-graph. Except for the root, every connected component is directly connected to only one other component. The root is an initiating component (does not receive) and is directly connected to one or more other components.

$\mathcal{M}$: **Hierarchy system measure,** $\mathcal{M}({}_{HO}\mathfrak{S})$, $=_{df}$ a measure of a *tree*.

$$\mathcal{M}({}_{HO}\mathfrak{S}) =_{df} [(\Sigma_{i=1,\ldots,n}[(|r_{d(branch)}(e) \geq 1| \times |\max(r_{d(walk)}(e) + 1)|) \div \log_2|\mathcal{A}_i|]) \div n] \times 100$$

9. Heterarchical Orderness: A pair of components is associated if they are either adjacent or non-adjacent and have a directed connection between them. The length of the path between associated components is greater than or equal to one. Components are heterarchy-connected if they are associated and each associated pair has a two-way connection, or if a component is a leaf (receiving only) and associated

$\mathcal{M}$: **Heterarchy system measure,** $\mathcal{M}({}_{HA}\mathfrak{S})$, $=_{df}$ a measure of initiating and receiving associated component affect-relations, or receiving associated (leaf) component affect-relations.

$$\mathcal{M}({}_{HA}\mathfrak{S}) =_{df} [(\Sigma_{i=1,\ldots,n}[(|r_{d(I,T)}(e) \geq 1| + |r_{d(leaf)}(e) \geq 1|) \div \log_2|\mathcal{A}_i|]) \div n] \times 100$$

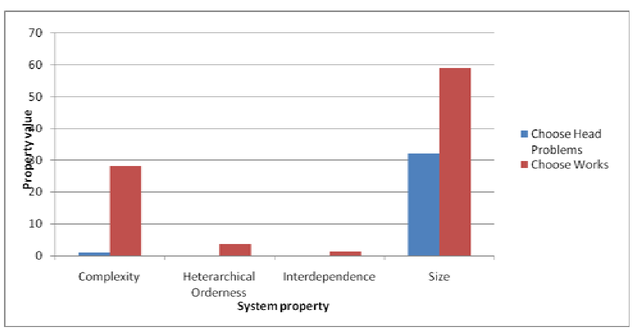
Results

Structural differences arising from choice

The activity pattern of *Head Problems* followed by the long *Morning Work Period* was relatively stable across the ten observation days. Students had to complete the worksheets prescribed by teachers during *Head Problems* but could choose the *Works* they wanted to do, and whether they wanted to work on them individually or collaboratively during the *Morning Work Period*. The different structural configurations with respect to *Choice* resulted in *Complexity* being substantially lower during *Head Problems* as only one *Choice* affect relation was present (See Figure 1); being that between the teacher and the problems assigned to students. This is represented as an affect relation set {t1, a100} where a100 denotes the *Head Problems* for that particular day. In comparison, the *Morning Work Period* found *Choice* affect relations occurring between each student and the *Works* they selected, thereby resulting in a higher level of *Complexity*. This is modeled by the affect relation set:

{(s1,a1) (s2,a2) (s3,a3) (s4,a4) (s5,a5), (s6,a25), (s7, a26), (s8,a29), (s9,a6) (s10,a7) (s11,a8) (s12,a9) (s13,a10) (s14,a11) (s15,a12) (s16,a13) (s17,a14) (s18,a15) (s19,a16) (s20,a17) (s21,a18) (s22,a19) (s24,a20) (s25,a21) (s26,a22) (s27,a27) (s27,a23) (s28,a28) (s28,a23)}.

Figure 1. Comparison of structural configurations with respect to student choice of learning activity



Interdependence was created when each student initiated and received *Choice* connections by selecting their work partners, and negotiating how they wanted to work on the project. For example, two students (s27 and s28) collaborated on a paper about the Olympics (a23). This is represented by the ordered pairs (s27, a23) and (s28, a23). They also completed other individual *Works* during this time i.e. (s27, a27), (s28, a28). The *Morning Work Period* also had more *Works* (a1 to a28) that could be chosen by students, resulting in a larger *Size* (number of components in a system). As a result, the system showed more *Heterarchical Orderness* as *Choice* relationships were not prescribed hierarchically from one source, i.e. the teacher.

Structural configurations with respect to Instructional affect relations

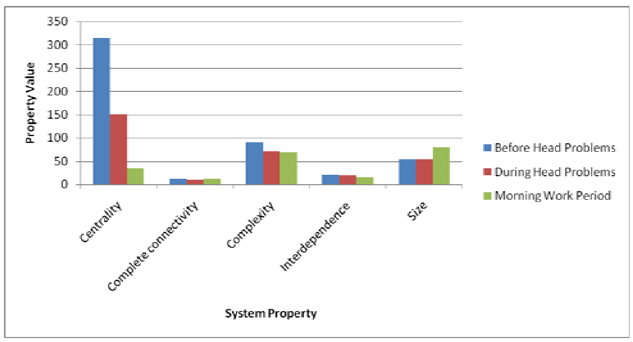
Instructional affect relations were created between teachers and students; and between students when they exchanged instructional content. Differences in *Instructional* affect relations were found during three time periods: before starting *Head Problems*, during *Head Problems* and during the *Morning Work Period*.

Direct instruction was the primary mode of instruction used before teachers distributed *Head Problems* worksheets for the day. Children would be gathered at one side of the classroom where the requirements of the worksheet were reviewed with a short refresher of related contents. This usually lasted for about 15 minutes, and is represented by the affect relation set:

{(t1,s1) (t1,s2) (t1,s3) (t1,s4) (t1,s5) (t1,s6) (t1,s7) (t1,s8) (t1,s9) (t1,s10) (t1,s11) (t1,s12) (t1,s13) (t1,s14) (t1,s15) (t1,s16) (t1,s17) (t1,s18) (t1,s19) (t1,s20) (t1,s21) (t1,s22) (t1,s23) (t1,s24) (t1,s25) (t1,s26) (t1,s27) (t1,s28) (t2,s1) (t2,s2) (t2,s3) (t2,s4) (t2,s5) (t2,s6) (t2,s7) (t2,s8) (t2,s9) (t2,s10) (t2,s11) (t2,s12) (t2,s13) (t2,s14) (t2,s15) (t2,s16) (t2,s17) (t2,s18) (t2,s19) (t2,s20) (t2,s21) (t2,s22) (t2,s23) (t2,s24) (t2,s25) (t2,s26) (t2,s27) (t2,s28) (t3,s1) (t3,s2) (t3,s3) (t3,s4) (t3,s5) (t3,s6) (t3,s7) (t3,s8) (t3,s9) (t3,s10) (t3,s11) (t3,s12) (t3,s13) (t3,s14) (t3,s15) (t3,s16) (t3,s17) (t3,s18) (t3,s19) (t3,s20) (t3,s21) (t3,s22) (t3,s23) (t3,s24) (t3,s25) (t3,s26) (t3,s27) (t3,s28) (s1,t1) (s2,t1) (s3,t1) (s4,t1) (s5,t1) (s6,t2) (s7,t2)}

When direct instruction was used, *Instructional* affect relations were initiated from the teacher to each student resulting in a high level of *Centrality* (see Figure 2) because the teacher was primary-initiating.

Figure 2. Comparison of structural configurations with respect to *instructional* relations



Despite the high level of *Centrality*, there was a corresponding presence of *Complete Connectivity* and *Interdependence* because teachers always called upon students to share their knowledge, and used their answers to reinforce important concepts. Comparison of observation data during this time found that about 5 to 7 students were called upon during these mini-lecture sessions. This is modeled with ordered pairs (s1,t1) (s2,t1) (s3,t1) (s4,t1) (s5,t1) (s6,t2) (s7,t2) in the affect relation set.

Work-time during *Head Problems* was structurally similar to that for the *Morning Work Period* except that students had no choice over their learning activity. This is modeled by the affect relation set:

{(a100,s1) (a100,s2) (a100,s3) (a100,s4) (a100,s5) (a100,s6) (a100,s7) (a100,s8) (a100,s9) (a100,s10) (a100,s11) (a100,s12) (a100,s13) (a100,s14) (a100,s15) (a100,s16) (a100,s17) (a100,s18) (a100,s19) (a100,s20) (a100,s21) (a100,s22) (a100,s23) (a100,s24) (a100,s25) (a100,s26) (a100,s27) (a100,s28) (s21,t2) (t2,s21) (s22,t2) (t2,s22) (s1,t3) (t3,s1) (s2,t3) (t3,s2) (s28,t3) (t3,s28) (s28,s10) (s18,s19) (s19,s18) (s4,t1) (s4,t2) (s4,t3) (s4,computer1) (s4,s1) (s4,s2) (s4,s3) (s4,s5) (s4,s6) (s4,s7) (s4,s8) (s4,s9) (s4,s10) (s4,s11) (s4,s12) (s4,s13) (s4,s14) (s4,s15) (s4,s16) (s4,s17) (s4,s18) (s4,s19) (s4,s20) (s4,s21) (s4,s22) (s4,s23) (s4,s24) (s4,s25) (s4,s26) (s4,s27) (s4,s28)}

Centrality was also higher as compared to the *Morning Work Period* (See Figure 2) since a larger number of *Instructional* affect relations originated from *Head Problems* assignments, as shown by ordered pairs (a100,s1), (a100,s2)…(a100,s28). *Complete Connectivity* arose out of *Instructional* affect relations that were formed when students sought help from teachers and peers to solve *Head Problems*. Teachers rarely told students answers directly but used this time for personalized coaching, thereby creating bi-directional *Instructional* affect relations between teachers and students, as modeled by ordered pairs such as (s21,t2), (t2,s21) and (s1,t3), (t3,s1). *Complete Connectivity* was also observed between students. For example, small groups of two or three could be gathered around the teachers' tables clarifying a question about the *Head Problems*. This is modeled by ordered pairs (s1,t3) (t3,s1) (s2,t3) (t3,s2) (s28,t3) (t3,s28) in the affect relation set where s1,s2, and s28 initiated *Instructional* affect relations with t3. s28 then returned to her desks and instructed another, as modeled by (s28,s10), where s28 forms *Instructional* affect relations with s10 by explaining what she learned from discussion with the teacher. Teachers also created opportunities for *Interdependence* by encouraging students to raise questions about the assigned *Head Problems*, especially when they found mistakes. They believed that this motivated buy-in for undertaking challenging work and allowed students to initiate suggestions for improving the contents they were working with.

At first sight, the *Morning Work Period* could seem unstructured or even chaotic as each teacher and student seemed to be engaged in their own agendas. Five or six students could be typing up book reports on the computers while two or three others are working on Math workbooks at their desks. One teacher could be searching for a book with two students in the library; the second engaged in an individual feedback session while the third was grading assignments at her desk. A significant difference between *Head Problems* and the *Morning Work Period* was that *Instructional* affect relations with students originated from the different *Works* they chose to be engaged in, thereby resulting in a much lower value for *Centrality* as compared to the other two time periods. This is modeled by (a1,s1)…(a28, s28) in the *Instructional* affect relation set for the *Morning Work Period*:

{(a1,s1) (a2,s2) (a3,s3) (a4,s4) (a5,s5) (a5,s7) (a6,s6) (a8,s8) (a9,s9) (a10,s10) (a11,s11) (a12,s12) (a13,s13) (a14,s14) (a15,s15) (a16,s16) (a17,s17) (a18,s18) (a19,s19) (a20,s20) (a21,s21) (a22,s22) (a23,s23) (a24,s24) (a25,s25) (a26,s26) (a27,s27) (a28,s28) (computer1,s12) (s12,computer1) (computer2,s13) (s13,computer2) (computer3,s14) (s14,computer3) (computer4,s15) (s15,computer4) (computer5,s16) (s16,computer5) (computer6,s6) (s6,computer6) (s27, computer7) (computer7, s27) (s28, computer7) (computer7, s28) (books1,s14) (s14, books1) (books2,s20) (s20,books2) (t1,s1) (s1,t1) (t1,s2) (s2,t1) (t1,s3) (s3,t1) (t2,s6) (s6,t2) (t2,s9) (s9,t2) (t3,s19) (s19,t3) (t3,s20) (s20,t3) (t3,s21) (s21,t3) (s4,s5) (s5,s4) (s27,s28) (s28,s27)}

Size was also larger during the *Morning Work Period* (see Figure 2) because individual *Works* and learning resources provide content information to support student learning. These are modeled by ordered pairs such as (computer1, s12) (s12, computer1), and (books1, s14) (s14, books1). Bi-directional *Instructional* affect relations were created as students searched for and received content information from these resources. The *Morning Work Period* was also a time where teachers met individually with students to provide feedback on their projects. These interactions are illustrated by the bi-directional connections occurring between teachers and students such as (t,s1) (s1,t1). The feedback process was described by one teacher as a time where "most of the teaching happens." A meeting could sometimes take up to 45 minutes where teachers not only clarified misconceptions but also provided support by recommending books and resources that help students improve their projects. This thorough feedback process contributed to *Complete Connectivity* and *Interdependence* between teachers and students in terms of *Instructional* affect relations.

The flexibility for students to engage in collaborative projects also created opportunities for *Interdependence* in *Instructional* affect relations during this time. For example, s4 and s5 chose to help each other check their drafts for a Science project on the topic of Convection. They were observed to be asking each other questions related to their drafts, thereby forming bi-directional *Instructional* affect relations as shown by (s4,s5) (s5,s4). At a computer station, s27 and s28 were found to be looking up information on the World Wide Web for a writing project on the Olympics, thereby create *Instructional* affect relations between themselves and computer resources. Despite increased opportunities for collaboration, *Interdependence* during the *Morning Work Period* was lower than the other two time periods because it was left to the sporadic intent of students.

Structural configurations with respect to *Support* affect relations

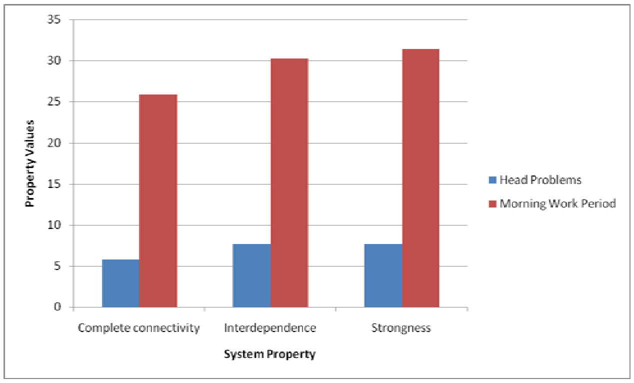
Even though *Instructional* affect relations were predominant, *Support* affect relations were found to coexist with them. These involved interactions related to information that was required to support instruction but were not instructional in nature. During *Head Problems*, such interactions usually involved the clarification of work instructions as modeled by the following affect relation set:

{(s1,t1) (s2,t1) (s4, t1) (t1,s1) (t1,s2) (t1,s3) (t1,s4) (t1,s5) (t1,s6) (t1,s7) (t1,s8) (t1,s9) (t1,s10) (t1,s11) (t1,s12) (t1,s13) (t1,s14) (t1,s15) (t1,s16) (t1,s17) (t1,s18) (t1,s19) (t1,s20) (t1,s21) (t1,s22) (t1,s23) (t1,s24) (t1,s25) (t1,s26) (t1,s27) (t1,s28) }

In comparison, *Support* affect relations were more predominant during the *Morning Work Period* as students were not constrained to doing the same activity at the same time (See Figure 3). This provided greater flexibility for students to engage in *Support* activities with each other, such as one student teaching another how to use the scanner. This is modeled by the interactions between s1, s2, s3 and the scanner in the *Support* affect relation set during the *Morning Work Period:*

{(s1,s2) (s3,s1) (s1,s3) (s3, scanner), (scanner,s1) (s10,s11) (s11, s10) (s23, s24) (s24,s23)(t1,s26) (t1,books4) (s26,t1) (s26,books4) (t2,s25) (s25,t2) (s7,books1) (s8,books2) (s14,computer1) (s15,computer2) (s16,computer3) (s17,computer4) (computer1,s14) (computer2,s15) (computer3,s16) (computer4,s17) (books1,s7) (books2,s8)}

Figure 3. Comparison of structural configurations with respect to *support* relations



Another type of *Support* affect relation that occurred naturally between students would be during the orientation of new students. For example, when approached by new student s11, s10 demonstrated how to clip a grading sheet to the *Head Problems* worksheet when handing it up. s23 served as a student mentor for s24 who was a visitor from the lower elementary class by showing her the format for citing sources in a research report. Teachers also provided support to students by helping them search for additional books and resources to support completion of *Works* as shown by interactions between t1, s26 and books4. As a result, *Complete Connectivity*, *Interdependence* and *Strongness* were higher during the *Morning Work Period* as there was a larger number and more variety in the types of *Support* relations that were present.

Structural configuration with respect to *Control* affect relations

Even though student autonomy was a feature of the Montessori classroom, Figure 4 showed that this did not preclude the need for control.

Figure 4. Structural properties relevant to *control* relations

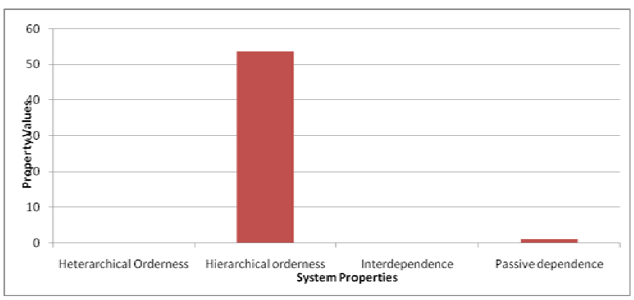


Figure 4 shows that *Control* affect relations were characterized by the presence of *Hierarchical Orderness* and *Passive Dependence*, which described connections whereby components received, rather than initiated relationships. *Heterarchical Orderness* and *Interdependence* were absent as *Control* was imposed on students without any means for negotiation. This is modeled by the affect relation set:

{(t1,s1) (t1,s2) (t1,s3) (t1,s4) (t1,s5) (t1,s6) (t1,s7) (t1,s8) (t1,s9) (t1,s10) (t1,s11) (t1,s12) (t1,s13) (t1,s14) (t1,s15) (t1,s16) (t1,s17) (t1,s18) (t1,s19) (t1,s20) (t1,s21) (t1,s22) (t1,s23) (t1,s24) (t1,s25) (t1,s26) (t1,s27) (t1,s28)}

Teachers initiated *Control* affect relations in four situations: To focus students for instructional purposes; for disciplinary reasons when trying to help students stay on task during the *Morning Work Period* and to help students transition between *Head Problems* and the *Morning Work Period*.

Impact on student motivation

Table 1 shows the average rating of respondents by motivation category.   Using the internalization process as outlined by Deci, Eghrari, Patrick and Leone (1994), these figures showed that respondents had a greater tendency to undertake learning activities because they perceived some personal value and identification with the learning goals (Identified Regulation) rather than because they felt compelled by external factors (External Regulation).

Table 1. Students' Motivation Level for Schoolwork

Type of motivation	Score (Beginning)	Score (End)
External Regulation	2.47	2.54
Introjected Regulation	3.04	2.88
Identified Regulation	3.13	3.12
Intrinsic Motivation	2.15	2.10

Note. n = 9

Motivation styles of teachers

The teachers' score on the *Problems in Schools Questionnaire* by motivational style is shown in Table 2.

Table 2. Teachers' Motivational Style

Motivational Style	Average Score
Highly autonomy supportive	46.33
Moderately autonomy supportive	28.67
Moderately controlling	23.00
Highly controlling	16.00

Note. n = 3, maximum possible score = 56

The three teachers varied in terms of their teaching experience in Montessori schools. The Head Teacher had 32 years of teaching experience, while the two assistant teachers had 4 and 1 year of teaching experience respectively. Regardless of the number of years they taught in a Montessori school, all the three teachers had the highest scores for the category related to *Highly Autonomy Supportive* and lowest scores for the *Highly Controlling* category.

Discussion

Autonomy support in the Montessori classroom

The results of this study show that the instructional methods employed by teachers were congruent with the basic Montessori philosophy of cultivating self-mastery. Regardless of whether students sought help for *Instructional* or *Support* issues, teachers consistently used these opportunities to help them arrive at their own answers for resolving problems, resulting in the presence of *Complete Connectivity* throughout *Head Problems* and the *Morning Work Period* in terms of *Instructional* and *Support* affect relations. This underlying philosophy for Montessori teaching accounts for why all the three teachers rated themselves as being *Highly Autonomy Supportive.*

This study also shows that *Complete Connectivity* in terms of *Instructional* affect relations could be created when teachers provide opportunities for students to contribute ideas and suggestions for improving the learning contents they are working with. This recognizes students as legitimate partners in the learning process, and impacts their willingness to learn challenging content. In terms of *Support* affect relations, a free-flowing work system such as that of the *Morning Work Period* provides scope for *Complete Connectivity* and *Interdependence* between students. When *Support* affect relations are less centralized and dependent upon the availability of teachers, it allows them to focus on personalized instruction. The structural organization of the *Morning Work Period* also increases the *Strongness* of connections between system components, providing opportunities for students to foster social relationships and relatedness, or secure connections with people (Stipek, 2002).

While Assor, Kaplan, Kanat-Maymon & Roth (2005)'s study found that controlling strategies predicted higher levels of anger and anxiety, this study found that being autonomy-supportive does not imply the absence of control. On the contrary, discipline and control are periodic and necessary activities for maintaining engagement on learning goals. They need not necessarily result in negative affect with students if used appropriately.

MAPSAT: Map & Analyze Patterns & Structures Across Time

The measures of classroom structure reported in this study are new. Originally, Frick (1990) devised analysis of patterns in time (APT) as a methodology for measuring system dynamics – i.e., maps of temporal configurations or processes. APT has since been extended by Thompson (2006) to include analysis of patterns in configurations (APC). Configural patterns characterize *structures* in education – i.e., how education is organized, or relations between parts and whole. Together, this approach to mapping of data and methods of analysis is called Map and Analyze Patterns and Structures Across Time (MAPSAT). In conventional measurement, variables are *measured separately for each case*, and then some method is used to relate the separate measures statistically for a set of cases (e.g., correlation, ANOVA, regression, and other linear models approaches). On the other hand, in MAPSAT, the researcher constructs configurations. A configuration is a temporal or structural map that describes a given case at a given time (the case is viewed as a single *system*). Then properties of those maps are determined from either sequences of event changes (APT) or from digraphs of affect relations (APC). Values of these temporal or structural properties *of a case* is the system measure. For example, in the present study we determined the value of the property, interdependence, of affect relations during the morning work period in the Montessori classroom we observed. This is a measure of the configuration of affect relations. For interdependence, it is a measure of the pattern of components that both initiate and receive.

MAPSAT also includes APT. Instead of a structural map, through observation we create a temporal map of category changes in classifications that describe *changes* in system events. APT was not done in the current study. However, in Frick (1990) one of the temporal patterns was student engagement when there was interactive or direct instruction. The mean likelihood of that temporal event pattern was 0.97, which means that if interactive instruction was occurring in a classroom, then the probability of student engagement was very high within each of the 25 learning environments for elementary students observed in his study.

Axiomatic Theories of Intentional Systems (ATIS: Thompson, 2005a; 2005b; 2005c; 2006; 2007) provides the theoretical framework for MAPSAT. APT was designed originally to measure system dynamics, whereas APC has been more recently designed to measure system structure. ATIS has the potential to help us better understand and predict the behavior of educational systems. More information on ATIS is available in reports by Thompson (2005a; 2005b; 2005c; 2006; 2007).

Limitations and suggestions for future research

The first limitation of this study is that only one Montessori classroom was studied. Comparison and contrast of structural configurations between systems was not possible, thereby limiting generalizability. The second limitation is that only about a third of the students could be surveyed. The motivational profiles of students may not have been similar for students whose parents did not allow us to collect data on them. Therefore, the student survey results need to be interpreted with caution.

For future research, this study could be replicated in more Montessori and K-12 classrooms and the structural properties compared. The relevance of other structural systems properties such as *Compactness*, *Flexibleness*, *Weakness* and *Vulnerableness* towards explaining classroom configurations could also be explored to allow additional properties of classroom structure to be understood.

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