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Interventions shown to Aid Executive Function Development in Children 4–12 Years Old *

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Abstract

To be successful takes creativity, flexibility, self-control, and discipline. Central to all those are ‘executive functions,’ including mentally playing with ideas, giving a considered rather than an impulsive response, and staying focused. Diverse activities have been shown to improve children’s executive functions – computerized training, non-computerized games, aerobics, martial arts, yoga, mindfulness, and school curricula. Central to all these is repeated practice and constantly challenging executive functions. Children with worse executive functions initially, benefit most; thus early executive-function training may avert widening achievement gaps later. To improve executive functions, focusing narrowly on them may not be as effective as also addressing emotional and social development (as do curricula that improve executive functions) and physical development (shown by positive effects of aerobics, martial arts, and yoga).

What will children need to be successful? What programs are successfully helping children develop those skills in the earliest school years? What do those programs have in common?

Four qualities will probably be key to success - creativity, flexibility, self-control, and discipline. Children will need to think creatively to devise solutions never considered before. They’ll need working memory to mentally work with masses of data, seeing new connections among elements. They’ll need flexibility to appreciate different perspectives and take advantage of serendipity. They’ll need self-control to resist temptations, and avoid doing something they’d regret. Tomorrow’s leaders will need to have the discipline to stay focused, seeing tasks through to completion.

All of those qualities are ‘executive functions’ (EFs), the cognitive control functions needed when you have to concentrate and think, when acting on your initial impulse would be ill-advised. EFs depend on a neural circuit in which prefrontal cortex is central. Core EFs are cognitive flexibility, inhibition (self-control, self-regulation), and working memory (1). More complex EFs include problem-solving, reasoning, and planning. EFs are more important for school readiness than is IQ (2). They continue to predict math and reading competence throughout all school years (e.g., 3). Clearly, to improve school readiness and academic success, targeting EFs is crucial. EFs remain critical for success throughout life (in career [4] and marriage [5]) and for mental and physical health (6, 7).

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Children with worse self-control (less persistence, more impulsivity, and poorer attention regulation) at ages 3–11 tend to have worse health, earn less, and commit more crimes 30 years later than those with better self-control as children, controlling for IQ, gender, social class, and more (8). Since “self-control’s effects follow a [linear] gradient, interventions that achieve even small improvements in self-control for individuals could shift the entire distribution of outcomes in a salutary direction and yield large improvements in health, wealth, and crime rate for a nation” (8, p.2694).

What programs have been shown to help young children develop these skills?

There is scientific evidence supporting six approaches for improving EFs in the early school years.

Computerized training (9)

The most researched approach, and one repeatedly found successful, is CogMed© computerized working-memory training (10–14) which uses computer games that progressively increase working-memory demands. Youngsters improve on games they practice and this transfers to other working-memory tasks. Groups studied have been typically-developing children (13), and those with ADHD (11, 14) or poor working-memory spans (10). Benefits usually don’t generalize to unpracticed EF skills. Three studies (10–12) included controls who played the same training games without difficulty increasing; those controls did not show the same gains.

Two studies looked 6 months later and found EF benefits remained (10, 14). For math, gains were not evident immediately, but were evident 6 months later (10).

In a double-blind, randomized-control trial with multiple training- and transfer-tasks, one group of 4-year-olds was trained on working memory (using CogMed©), one on non-verbal reasoning, another on both, and a control group on both but remaining at the easiest level. Those trained on working memory improved more on working-memory transfer tasks than did controls and those trained in reasoning improved more on reasoning transfer tasks than controls (12). Neither group showed transfer to the un-practiced skill (reasoning for the former, working memory for the later). The combined group showed less improvement on both (having received less practice on each). Transfers were narrow. Non-verbal analogical-reasoning training transferred to non-verbal analogical-reasoning on Ravens Matrices but not to non-verbal gestalt-completion on Ravens. Non-verbal working-memory training transferred to other measures of non-verbal working memory but not to the one measure of verbal working memory.

Efforts to use computer games to train inhibition have experienced limited success. Using the same dosage, duration, and frequency as CogMed© studies, improvements in 4 and 6-year-olds were found on only 2 of the 3 inhibition games practiced, with no transfers to un-practiced tasks (13). Perhaps the children were too young, training too brief, or training tasks not optimal.

After training with computer games that taxed working memory and/or inhibitory control (gradually increasing in difficulty) or that required visuo-motor control, 4- and 6-year-olds showed no cognitive benefits save one (15) -- improved matrices score (reasoning) on the K-Bit; nor did their parents report better EFs. However, more mature brain-electrical-responses during a selective-attention task were found after training (perhaps presaging later cognitive advances).

Hybrid of computer and non-computer games (9)

When children of 7–9 years were randomly assigned to reasoning or speed training with computerized and non-computerized games played individually and in small groups, with difficulty incrementing), improvements transferred to untrained measures of each, but were specific (16). Those trained on reasoning didn't improve on speed and those trained on speed didn't improve on reasoning relative to baseline.

Aerobic Exercise and Sports (9)

Aerobic exercise robustly improves prefrontal cortex function and EFs (17, 18). Although most studies involved adults and/or examined effects of a single bout of aerobic exercise, which may be transient, the conclusion finds support in three studies of sustained exercise in children.

Aerobic running (with exercises becoming more demanding over time) improved 8–12 year-olds' cognitive flexibility and creativity, and significantly more so than did standard physical education, yet didn't affect non-EF skills (19).

Davis et al. (20) randomly assigned sedentary, overweight 7–11 year-olds to no treatment, 20-minutes/day or 40-minutes/day of group aerobic games (running games, jump rope, basketball, and soccer), with an emphasis on enjoyment and intensity, not competition or skill enhancement. Only the high-dose aerobics group improved on EFs (only on the most EF-demanding measure) and math, compared with no-treatment controls. Dose-response benefits of aerobic exercise were found for the most difficult EF task and for math. Neither aerobics group improved more than controls on the EF skill of selective attention or on non-EF skills.

When 7–9 year-olds were randomly assigned to 2-hours of fitness training daily for the school year (aerobic activities for 70 minutes, then motor skill development) or no treatment, those who received fitness training showed more improvement in working memory than did controls, especially evident when working-memory demands were greater (21). However, working memory didn't differ significantly between the two groups at either pre- or post-test.

Suggestive evidence from studies of physical activity (22, 23) and music training (24, 25) indicates that exercising bimanual coordination may improve EFs. So far evidence shows no EF benefits from resistance training (26, 27). There are not yet studies of the benefits of sports for EFs to our knowledge. Sports might benefit EFs more than aerobic exercise alone, since besides improving fitness, sports challenge EFs (requiring sustained attention, working memory, and disciplined action) and bring joy, pride, and social bonding (it's known that sadness, stress, and loneliness impair EFs).

Martial Arts and Mindfulness Practices (9)

Traditional martial arts emphasize self-control, discipline (inhibitory control), and character development. Children getting traditional Tae-Kwon-Do training were found to show greater gains than children in standard physical education on all dimensions of EFs studied (e.g., cognitive [distractible—focused] and affective [quitting—persevering]) (28). This generalized to multiple contexts and was found on multiple measures. They also improved more on mental math (which requires working memory). Gains were greatest for the oldest children (Grades 4 & 5) and least for the youngest (K & Grade 1) and greater for boys than girls. This was found in a study where children 5–11 years old were randomly assigned by homeroom class to Tae-Kwon-Do (with challenge incrementing) or standard physical education. Besides including physical exercise, martial-arts sessions began with three

questions emphasizing self-monitoring and planning: Where am I (i.e., focus on the present moment)? What am I doing? What should I be doing? The later two questions directed children to select specific behaviors, compare their behavior to their goal, and make concrete plans for improvement. Unlike many studies that target disadvantaged children and/or those behind on EFs, children here were socioeconomically-advantaged, making the findings especially impressive.

Instructive findings are reported in a study with adolescent juvenile delinquents (29). One group was assigned to traditional Tae-Kwon-Do (emphasizing qualities such as respect, humility, responsibility, perseverance, and honor as well as physical conditioning; focusing on self-control and self-defense). Another group was assigned to modern martial arts (martial arts as a competitive sport). Those in traditional Tae-Kwon-Do showed less aggression and anxiety and improved in social ability and self-esteem. Those in modern martial arts showed more juvenile delinquency and aggressiveness, and decreased self-esteem and social ability.

After mindfulness training, greater EF improvements were found in 7–9 year-olds with initially-poorer EFs than those with initially-better EFs, compared with controls (who silently read) (30). Children with initially poor EFs showed EF improvements overall and in the components of shifting and monitoring, bringing their scores up to average. Both teachers and parents reported these improvements, suggesting they generalized across contexts. The mindfulness training sessions consisted of three parts: sitting meditation; activities to promote sensory awareness, attention regulation, or awareness of others or the environment; and a body scan. Demands on mindfulness increased over time as the first and third parts lengthened and the more goal-directed and less-reflective middle portion became briefer. Skills practiced in Parts 1 and 3 involved top-down control of attention (bringing attention to the present moment, noticing when attention had wandered [monitoring], and bringing it back non-judgmentally to the intended target).

There's some suggestion that yoga might help as well. Girls 10 and 13 years old were randomly assigned to yoga or physical training (31). Yoga training (physical training, relaxation, and sensory awareness) improved EFs, with improvements most evident when EF demands were greatest. Physical training (physical activity without mindfulness) produced no EF improvement.

Classroom Curricula (9, 32)

Two curricula that share important similarities have been shown to improve EFs. *Tools of the Mind (Tools)* is a curriculum for preschool and Kindergarten developed by Bodrova and Leong (33) based on Vygotsky (34). Vygotsky emphasized the importance of social pretend play for the early development of EFs. During pretend play, children must inhibit acting out of character, remember their own and other's roles, and flexibly adjust as their friends improvise. Such play exercises all three core EFs and is central to *Tools*. Children plan who they'll be in a pretend scenario, and the teacher holds them accountable for following through. Bodrova and Leong initially tried *Tools* as an add-on to existing curricula. Children improved on what they practiced in those modules, but benefits didn't generalize. For benefits to generalize, supports, training, and challenges to EFs had to be part of what children did all day at school, and therefore are interwoven into all academic activities.

Children are taught how to support nascent EFs by scaffolding with visual reminders (e.g. a drawing of an ear to remember to listen) and private speech. Instead of being embarrassed for being poor listeners, the simple drawing of an ear enables children to proudly be good listeners. As EFs improve, supports are gradually removed, gently pushing children to extend the limits of what they can do.

Tools was evaluated against another high-quality program using EF measures that required transfer of training (35). *Tools* 5-year-olds outperformed control children on both EF measures, which taxed all 3 core EFs, and especially on the more EF-demanding conditions. Thus the program with more play produced better EFs than the one with more direct instruction. One school, so impressed by how much better *Tools* children were doing, withdrew from the study and switched all classes to *Tools*.

Montessori

(36) curriculum doesn't mention EFs but what Montessorians mean by "normalization" includes having good EFs (37). Normalization is a shift from disorder, impulsivity, and inattention to self-discipline, independence, orderliness, and peacefulness. Montessori classrooms have only one of any material so children learn to wait until another child is finished. Several Montessori activities are essentially walking meditation.

As in *Tools*, the teacher carefully observes each child (when a child is ready for a new challenge, the teacher presents one). As in *Tools*, whole-group activities are infrequent; learning is hands-on, often with ≥ 2 children working together. In *Tools* children take turns instructing or checking one another. Cross-age tutoring occurs in Montessori mixed 3-year age-groups. Such child-to-child teaching has been found repeatedly to produce better (often dramatically better) outcomes than teacher-led instruction (38–40).

Children chosen from a lottery to enter a Montessori public school approved by the Association Montessori Internationale (AMI) were compared to those also in the lottery but not chosen, at the end of Kindergarten (age 5) and end of Grade 6 (age 12) (41). At age 5, Montessori children showed better EFs than peers attending other schools. They performed better in reading and math and showed more concern for fairness and justice. No group difference was found in delay of gratification. At age 12, on the only measure related to EFs, Montessori children showed more creativity in essay writing than controls. They also reported feeling more of a sense of community at school.

Add-ons to Classroom Curriculum (9, 32)

Two programs with different philosophies, both intended to complement existing curricula, improve EFs. **PATHS** (42) (Promoting Alternative Thinking Strategies) trains teachers to build children's competencies in self-control, recognizing and managing feelings, and interpersonal problem-solving. Young children experience and react to emotions before they can verbalize them and often react impulsively without top-down control. Thus training in verbalizing one's feelings and practicing conscious self-control strategies (e.g., waiting before acting and self-talk) are emphasized. When children get upset they should stop, take a deep breath, say what the problem is and how they feel, and construct an action plan. Teachers are taught techniques to generalize skills learned during PATHS lessons to other contexts during the school day,

After a year of PATHS, 7–9 year-olds showed better inhibitory control and cognitive flexibility than control children (43). Children who showed greater inhibitory control at post-test showed fewer internalizing or externalizing behavior problems one year later.

Using a different approach, **Chicago School Readiness Project** (CSRP), provided Head Start teachers with extensive behavior management training and suggestions for reducing their stress. Strategies taught were similar to those in *Incredible Years* (44) (e.g., implement clearer rules and routines, reward positive behavior, and redirect negative behavior). CSRP intentionally didn't train teachers in academic instruction, nor provide curricula on academic subjects. It emphasized developing verbally-skilled strategies for emotion regulation. Mental

health consultants conducted stress-reduction workshops for teachers all year. Children with the worst externalizing behavior received 1-on-1 counseling.

Raver, who directs CSRP, headed a randomized-control trial (45, 46) with 18 of 35 Head-Start classrooms assigned to CSRP. CSRP teachers provided better-managed and more emotionally-supportive classrooms than control teachers. EFs (attention, inhibition, and experimenter-rated impulsivity) of 4-year-olds in CSRP classes improved over the year and significantly more so than did EFs of controls. CSRP didn't affect delay of gratification, however. CSRP children improved in vocabulary, letter-naming, and math, and significantly more than controls. CSRP's improvement of academic skills was mediated largely via its improvement of EFs. EFs in the spring of preschool predicted achievement 3 years later in math and reading (47).

What lessons can be learned about what aids EF development in young children from these six approaches?

(a) Those with initially poorest EFs gain the most. Lower-income, lower working-memory span, and ADHD children, and, in one study, boys (who often have poorer inhibitory control than girls [8]) generally show the most EF improvement from any program. Early EF training is thus an excellent candidate for leveling the playing field and reducing the achievement gap (48) between more- and less-advantaged children. EFs predict later academic performance (3), so as go EFs, so goes school readiness and academic achievement.

(b) The largest differences between those in programs that improve EFs and control participants are consistently found on the most demanding EF measures. Everyone does fine when EF demands are less. Group differences are clearest when significant executive control is needed. **(c)** EFs must be continually challenged to see improvements. Groups assigned to the same program, but without difficulty increasing, do not show EF gains.

(d.1) Studies of curricula (35, 41) and curricula-add-ons (43, 45, 46) demonstrate that EFs can be improved even at 4–5 years of age, by regular teachers (given training and support) in regular classrooms without expensive equipment. **(d.2)** There are suggestions that computer training (10–14) and martial arts (28) may benefit children of 8–12 more than children of 4–5.

(e) Computer training has been shown to improve working memory and reasoning, but it's unclear whether it can improve inhibitory control. Other approaches report improvement in inhibitory control as assessed by selective attention (e.g., Flanker) or response inhibition (e.g., go/no-go), but none report improvement in the inhibitory control needed to delay gratification.

(f) EF training appears to transfer, but the transfer is narrow. Working memory training improves working memory but not inhibition or speed. If the training was only with visual-spatial items, there's little transfer to verbal material. EF gains from martial arts or school curriculum may be wider because the programs themselves address EFs more globally; the transfer may not be wider, rather the programs address more EF components. **(g)** Exercise alone may not be as efficacious in improving EFs as exercise-plus-character-development (traditional martial arts [28]) or exercise-plus-mindfulness (31).

(h) Many different activities can improve EFs, probably including ones not yet studied (such as music training or sports). One key element is a child's willingness to devote time to the activity. Similarly, curricula need to address EFs throughout the day, not only in a module.

Repeated practice produces the benefits. Even the best activity for improving EFs if done rarely produces little benefit.

(i.1) Computer training has the advantage it can be done at home. As computer training incorporates more EF components, benefits will likely be seen more widely. These tend to be short-duration interventions, however, as interest in the games wanes and the games' highest levels are reached. (i.2) Martial arts, yoga, aerobic, or mindfulness activities can be done after school. (i.3) Since i.1 and i.2 cost money, they are not possible for all families. Public school curricula hold the greatest promise for accessibility to all, intervening early enough to get children on a positive trajectory from the start, and affecting EFs most broadly. Martial arts, yoga, aerobic, or mindfulness activities could be incorporated into school curricula. Though schools are curtailing physical education and the arts, evidence indicates that the opposite is probably needed for the best academic results.

The four curricula-based programs shown to enhance EF development have many commonalities (see Table 1). We'd like to highlight two: They don't expect young children to sit still for long. Such expectations are not developmentally-appropriate, teacher-student tension, and some children coming to dread school and/or being wrongly labeled as having ADHD. Second, the programs tend to reduce stress in the classroom, cultivate joy, pride, and self-confidence, and foster social bonding, all of which support efforts to improve EFs and academic achievement.

Stress (49), loneliness (50) and not being physically fit (17) impair prefrontal cortex function and EFs. The best approaches to improving EFs and school outcomes will probably be those that (a) engage students' passionate interests, bringing them joy and pride, (b) address stresses in students' lives, attempting to resolve external causes and strengthen calmer, healthier responses, (c) have students vigorously exercise, and (d) give students a sense of belonging and social acceptance, in addition to giving students opportunities to repeatedly practice EFs at progressively more-advanced levels. The most effective way to improve EFs and academic achievement is probably not to focus narrowly on those alone, but to also address children's emotional and social development (as do all 4 curricular-based programs that improve EFs) and children's physical development (aerobics, martial arts, and yoga).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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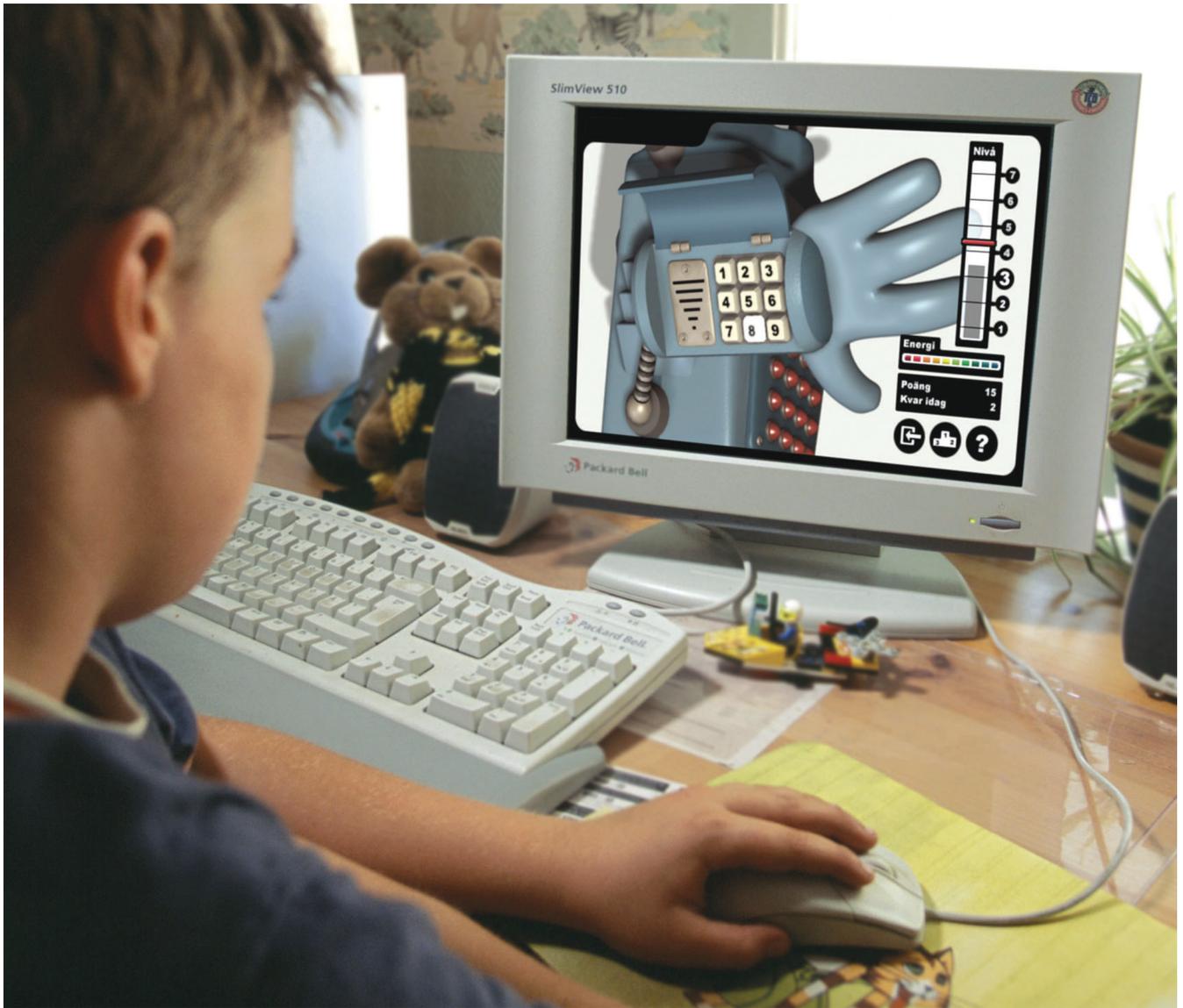


Figure 1.
A teen working at a CogMed© game.



Figure 2.
A child demonstrating a Tae-Kwon-Do stance.



Figure 3. Walking Meditation in Montessori can be simply walking on a line, walking on it without spilling water in a spoon or without letting your bell ring.

Table 1

	Toots of the Mind	Montessori	PATHS	CSRP
Developed by	Elena Bodrova & Deborah Leong (33)	Maria Montessori (37)	Carol Kusché & Mark Greenberg (43)	Cybele Raver (47)
Based on	Vygotsky (34)	Montessori (37)	Affective-Behavioral-Cognitive-Dynamic (ABCD) model (6)	Incredible Years (46)
Ages it is intended for (in years)	3–6 (Preschool & K)	0–18 (Infancy-Grade 12)	3–12 (Presch – Grade 6)	3–5 (Preschool)
Academic Content (e.g., reading and math) or just targets socio-emotional competence &/or EFs	both – a complete curriculum	both – a complete curriculum	integrated into a curriculum-only targets socio-emotional competence & EFs	complements a curriculum – targets self-regulation
EFs challenged all day, not just in an isolated module	yes	yes	yes	no
Cognitive, social, & emotional dev. seen as fundamentally intertwined	yes	yes	yes	no
Oral language is particularly targeted for development in young children	yes	yes	yes	no
Self-talk (private speech) is particularly encouraged in young children	yes	no	yes	no
Scaffolds (supports) are provided so children are far more likely to succeed than fail	yes	yes	yes	yes
Reprimand frequency	rare	virtually never	rare	rare
Extrinsic rewards used? (e.g. stickers)	no	no	no	yes
Planning by child is an important element	yes	yes	yes (though not in preschool)	no
Individualized pacing & instruction	yes	YES	no	no
Child-to-child tutoring	take turns as doer & checker	cross-age tutoring in mixed-age classrooms	no	no
Teacher as scientist & observer, constantly asking what new challenge or assistance does a given child need	yes	yes	no	no
Amount of teacher training needed	12 days of workshops over 2 years; 12 days of in-classroom follow up	1–2 years full-time plus in-service refreshers	2 days of workshops; classroom observations for 30 min/ week/ 30 weeks	12 days spread over 20 wks: 30 hrs in workshops; 4–4 hrs; wk for 20 wks get mentoring
Play is given a prominent role	Yes; especially mature social dramatic play	Playfulness, originality, creativity are encouraged; but rather than play at activities like cooking, children cook; no social dramatic play	Play is given a role in presch & K but not later	no
Active, hands-on learning; little whole-group activity ²				
Even preschoolers often work in 2- or 3-somes, or alone	yes	yes	somewhat with presch & K but not later	no
Character dev. (kindness, helpfulness, empathy) is a priority	yes	yes	yes	yes

	Toots of the Mind	Montessori	PATHS	CSRP
Emphasis on labeling and identifying feelings	yes	no	YES	YES
Awards & Honors received	<ul style="list-style-type: none"> • An Exemplary Innovation - International Bureau of Education of UNESCO 	<ul style="list-style-type: none"> • The widest geographical spread of any educational program. Currently in 117 countries across 6 continents. 	<ul style="list-style-type: none"> • Model Program - Blueprints Project for the Center for the Study & Prevention of Violence, Univ. of Colorado • Model Program - KidsMatter Australian Primary Schools Mental Health Initiative • Highly Rated Program - SAMHSA's National Registry of Evidence-based Programs & Practices • Best Practices Program-Centers for Disease Control & Prevention (CDC) • Promising Program - US Dept. of Ed., Safe & Drug-Free Schools • Promising Program – US Surgeon General's Report on Youth Violence 	

¹The "Montessori" name is not copyrighted; anyone can claim their school is a Montessori School. The characteristics above usually characterize high-quality, authentic Montessori programs, especially the combination of each child freely choosing what to work on and where (the floor, at a table, or outside the room), while the teacher carefully observes each child's activities, challenging and helping each to progress. Morning and afternoon sessions are uninterrupted by scheduled activities, so children can work on something as long as they like. Curiosity and interest are valued over finding single answers. The walls are uncluttered; the environment simple but attractive. There is a calm and peaceful atmosphere, with most children in deep concentration on their activities. Large class size is no problem; indeed classes of 30–40 are preferred over classes of 15–20 because only when the teacher: child ratio is sufficiently large to older children perceive the need to help instruct younger ones, and such child-to-child mentoring is greatly valued.

²'Whole-group' usually means the teacher teaching the whole class together. Children are expected to sitting quietly and attentively, sometimes for extended periods.