Appendix A

Source Information, Methodological Characteristics, and Intervention Characteristics

Article	Journal/University	Design	Interventionist	DV	Math concept	General	Main
Agrawal (2013, Study 1)	George Mason University[a]	MBD-P	Researcher	% conceptual steps; min. complete	Fractions	No Manip.	4 weeks
Agrawal (2013, Study 2)	George Mason University[a]	MBD-P	Researcher	% procedural steps; min. complete	Fractions	No Manip.	2 weeks
Bouck et al. (2014)	J. of Aut. & Dev. Dis.	AT	Researcher	% accurate problems; % ind. steps	Computation	Behavior	Check
Bouck, Bassette, et al. (2017)	J. of Sped. Tech.	MPD-P	Researcher	% accurate problems; % ind. steps	Fractions	—	2 weeks
Bouck, Chamberlain, & Park (2017)	Ed. & Train. in Aut. & Dev. Dis.	AT	Researcher	# correct problems; min. complete	Computation	No Manip.	—
Bouck, Park, & Nickell (2017)	Res. in Dev. Dis.	MPD-P	Researcher	% accurate problems	Money	—	2 weeks
Bouck, Park, et al. (2017)	Res. in Dev. Dis.	MPD-P	Researcher	% accurate problems	Fractions	—	1–2 weeks
Bouck et al. (2018)	Focus on Aut. & Other Dev. Dis.	MPD-B	Researcher	% accurate problems	Place value; Basic facts	—	3 weeks
Browder, Jimenez, Spooner, et al. (2012)	Ed. & Train. in Aut. & Dev. Dis.	MPD-B	Teacher	# correct responses	Geom.; Alg.; Data Analysis; Money	Behavior	2–3 weeks
Browder, Jimenez, & Trela (2012)	Res. & Pract. for Persons with Sev. Dis.	AB	Researcher, Teacher, Para.	# correct responses	Early num.	—	—
Browder et al. (2018)	J. of Sped.	MPD-P	Teacher	# correct steps; # correct problems	Prob. solving	Behavior	1 week
Burns et al. (2015)	LD Res. & Pract.	MBD-P	Researcher	# correct digits	Early num.	—	—
Cass et al. (2003)	LD Dis. Res. & Pract.	MPD-P	Teacher	% accurate problems	Per.; Area; Vol.	—	3 weeks

Cihak & Grim (2008)	Res. in ASD	MPD-B	Teacher	% accurate problems	Money	Setting	6 weeks
Denny & Test (1995)	Ed. & Treat. of Children	MBD-P	Researcher	# correct problems	Money	—	10 weeks
Flores (2009)	Prev. School Failure	MPD-P	Researcher	# correct digits	Computation	—	4 weeks
Flores (2010)	Rem. & Sped.	MPD-P	Researcher	# correct digits	Computation	—	6 weeks
Flores, Hinton, & Schweck (2014)	LD Res. & Pract.	MPD-B	Researcher	# correct digits	Computation	—	6 weeks
Flores, Hinton, & Strozier (2014)	LD Res. & Pract.	MPD-P	Researcher	# correct digits	Computation	Behavior	2 weeks
Flores, Hinton, & Burton (2016)	Prev. School Failure	MPD-P	Researcher	% correct problems	Prob. solving	—	8 weeks
Hardy (2014)	Vanderbilt University[a]	MPD-B	Researcher	% correct problems	Geom.; Patterning; Early Num.	Materials	1 month
Harris et al. (1995)	LD Res. & Pract.	MBD-P	Teacher	# correct digits	Basic facts	—	—
Hinton et al. (2016)	Prev. School Failure	MPD-B	Researcher	# correct responses	Early Num.	—	3 weeks
Hord & Xin (2015)	J. of Sped.	MPD-P	Teacher	% accurate problems	Per.; Area; Vol.	—	2 months
Hudson et al. (2016)	J. of Dev. & Phys. Dis.	MPD-P	Teacher	# correct responses	Early num.	—	—
Huntington (1994)	University of Georgia[a]	MPD-P	Researcher	% accurate responses	Prob. solving	Setting; Behavior	2 weeks
Jimenez et al. (2008)	Ed. & Train. in Dev. Dis.	MPD-P	Teacher	# correct steps	Algebra	Setting	NR
Jimenez & Kemmery (2013)	Ed. & Train. in Aut. & Dev. Dis.	MPD-P	Teacher	% mastered skills	Early num.	—	—
Jimenez & Staples (2015)	Ed. & Train. in Aut. & Dev. Dis.	MPD-P	Teacher	# mastered skills	Early num.	—	2 weeks
Maccini & Hughes (2000)	Ed. & Treat. of Children	MPD-P	Researcher	% accurate responses	Prob. solving	Behavior	NR
Maccini & Ruhl (2000)	LD Res. & Pract.	MPD-P	Researcher	% accurate responses	Prob. solving	Behavior	—
Mancl (2012)	University of Nevada, Las Vegas[a]	MPD-P	Teacher	% accurate problems	Prob. solving	Behavior	—

Mancl et al. (2012)	LD Res. & Pract.	MPD-P	Teacher	% accurate problems	Computation; Prob. solving	—	—
Marsh & Cooke (1996)	LD Res. & Pract.	MBD-P	Researcher, Teacher	# correct steps	Prob. solving	—	—
Miller & Mercer (1993)	LD Res. & Pract.	MBD-P	Teacher	# correct problems	Basic facts; money	—	1 week
Morin & Miller (1998)	Ed. & Treat. of Children	MBD-P	Teacher	% accurate problems	Basic facts	—	—
Mulcahy & Krezmien (2009)	Behavioral Disorders	MPD-P	Researcher	% accurate responses	Per.; Area; Vol.	Behavior	10 days
Ok & Bryant (2016)	LD Quartely	MPD-P	Researcher	# correct digits	Basic facts	—	2 weeks
Ozdemir (2018)	University of Buffalo[a]	MBD-P	Researcher	% accurate responses	Prob. solving	—	1 week
Reneau (2013)	West Virginia University[a]	MBD-P	Researcher	# correct problems	Prob. solving	—	10 days
Root et al. (2017)	Rem. & Sped.	MPD-P	Researcher	# correct steps	Prob. solving	No Prompting	NR
Satsangi & Bouck (2015)	LD Quarterly	MBD-P	Researcher	% accurate problems	Per.; Area; Vol.	No Manip.	2 weeks
Satsangi et al. (2016)	LD Quarterly	AT	Researcher	% accurate problems	Algebra	Best Treatment	—
Satsangi, Hammer, & Evmenova (2018)	LD Res. & Pract.	MBD-P	Researcher	% accurate problems	Algebra	No Manip.	3 weeks
Satsangi, Hammer, & Hogan (2018)	LD Quarterly	MPD-P	Researcher	% accurate problems	Algebra	—	2 weeks
Saunders (2014)	UNC Charlotte[a]	MDP-P	Researcher	# correct responses	Prob. solving	Behavior	—
Scheuermann et al. (2009)	LD Quarterly	MPD-P	Teacher	% accurate points	Prob. solving	Behavior	11 weeks
Sealander et al. (2012)	Assess. for Effective Inst.[b]	MBD-P	Teacher	# correct digits	Basic facts	Behavior	2 weeks
Shin (2013)	University of Texas-Austin	MPD-P	Researcher	% accurate problems	Prob. solving	—	2 weeks
Shin & Bryant (2017)	Rem. & Sped.	MPD-P	Researcher	% accurate problems	Prob. solving	—	—
Strickland & Maccini (2013b)	Rem. & Sped.	MPD-P	Researcher	% accurate problems	Per.; Area; Vol.; Algebra	Behavior	—
Strickland & Maccini	LD Quarterly	MPD-P	Researcher	% accurate problems	Algebra	Behavior	4–6 weeks

(2013a)							
Stroizer et al. (2015)	Ed. & Train. in Aut. & Dev. Dis.	MBD-B	Teacher	# correct problems	Computation; Basic facts	—	—
Yakubova et al. (2016)	J. of Aut. & Dev. Dis.	MPD-B	Researcher	% accurate problems	Basic facts; Early num.	—	3 weeks

Note. All studies published in academic journals unless designated. AT = alternating treatment design; MBD-P = multiple-baseline design across participants; MBD-B = multiple-baseline design across behaviors; MPD-P = multiple probe design across participants; MPD-B = multiple probe design across behaviors.

[a]Dissertation. [b]Multidisciplinary setting.

Appendix B

Manipulative Characteristics and Participant Characteristics

Article	Manipulatives	Perpetual	CRA	Duration: Sessions (min.)	Components B: behavior, A: Academic	n	Disability category (n)	Ages in yrs. (n)
Agrawal (2013, Study 1)	fraction circles, chips	Bland	Y	5–11 (35)	—	6	ASD (6)	8 (3); 9 (2); 10 (1)
Agrawal (2013, Study 2)	fraction circles, chips	Bland	Y	5–11 (35)	—	6	ASD (6)	8 (3); 9 (2); 10 (1)
Bouck et al. (2014)	base-ten blocks[b]	Bland	N	NR	—	3	ASD (3)	6 (1); 7 (1); 10 (1)
Bouck, Bassette, et al. (2017)	Fraction tiles	Bland	VRA	15–30 (10–15)	—	3	SLD (1); Mild ID (1); OHI/HI (1)	13 (2); 14 (1)
Bouck, Chamberlain, & Park (2017)	Base-ten blocks[b]	Bland	N	NR	—	3	Mild ID (2); SLD (1)	11 (1); 13 (1); 14 (1)
Bouck, Park, & Nickell (2017)	Money	Rich	Y	22 (20)	—	4	LD (2); ID (2)	12 (3); 13 (1)
Bouck, Park, et al. (2017)	Fraction tiles[a]	Bland	VA	8–16 (10–15)	—	4	OHI (1); Mild ID (1); ID (2)	13 (3); 14 (1)
Bouck et al. (2018)	Base-ten blocks[a], colored tiles	Bland	VRA	14–28 (55)	—	2	Mild ID (2)	12 (1): 13 (1)
Browder, Jimenez, Spooner, et al. (2012)	Paper money, Green/red chips	Bland/ Rich	N	NR	A: Task analysis least intrusive prompting	4	Mod ID (3); Sev ID (1)	11 (1); 13 (3)
Browder, Jimenez, & Trela (2012)	Counting (e.g. rubber worms)	Rich	N	96 (30)	—	7	Mod ID (5); ASD (1); ASD/Mod ID (1)	8 (2); 9 (2); 10 (2); 11 (1)
Browder et al. (2018)	Counting cubes,	Bland/	N	(30)	B: Select reinforcement after	8	Mod or Sev	10 (2); 11 (3);

	pennies, connect four, mancala board	Bland			sessions completed; A: Mod. schema-based inst.		ID (8)	12 (1); 13 (2)
Burns et al. (2015)	Dice	Rich	N	16 (20)	—	2	<25th% on MAP-M (2)	1st gr (1); 3rd gr (1)
Cass et al. (2003)	Geoboard	Bland	N	6–8 (15–20) 2 daily, 10 trials each	A: Counting up strategy	3	LD (3)	13 (1); 15 (1); 16 (1)
Cihak & Grim (2008)	Money	Rich	N	Extra setting, 1 (3 trials)	A: Least to most prompt hierarchy	4	ASD/Mod ID (4)	15 (1); 16 (2); 17 (1)
Denny & Test (1995)	Money	Rich	N	NR	A: One more than	3	Train MR (3)	17 (3)
Flores (2009)	Base ten blocks	Bland	Y	10–15 (30)	A: DRAW	6	SLD (3); At-risk (3)	8 (3); 9 (2); 10 (1)
Flores (2010)	Base ten blocks	Bland	Y	(30) 3x/wk	A: DRAW	6	Ar-risk (6)	8 (3); 9 (2): 10 (1)
Flores, Hinton, & Schweck (2014)	Base ten blocks	Bland	Y	10 lessons/ behavior	A: RENAME	3	At-risk (3)	8 (1); 9 (2)
Flores, Hinton, & Strozier (2014)	Base ten blocks	Bland	Y	(25) 3x/wk	A: Strategy inst. (FAST) Cognitive strategy inst.	4	SLD (4)	10 (2); 11 (2)
Flores, Hinton, & Burton (2016)	Cookies	Rich	Y	NR	A: Problem structure (schema-based)	3	At-risk (3)	9 (2); 10 (1)
Hardy (2014)	Foam shapes, unifix cubes, small rubber animals, pattern blocks w/ pictures cards	Bland/ Rich	N	4 (2 demo/beh)	—	3	At-risk (3)	4 (3)
Harris et al. (1995)	Paper plates & plastics counters	Bland	Y	21 lessons	A: Strategy inst. (DRAW, FAST DRAW)	13	SLD (12); EBD (1)	7 (1); 8 (8); 9 (4)
Hinton et al. (2016)	Counting manipulatives (e.g.,	Bland/ Rich	N	36	—	4	DD (2); At-risk (2)	5 (4)

	cars, jewels, cubes)							
Hord & Xin (2015)	Tape measures, wooden cubes, plastic unit squares	Bland	Y	7–10 (30)	A: Conceptual model-based problem solving	3	Mild ID (3)	11 (1); 13 (2)
Hudson et al. (2016)	Theme counters (e.g. race cars, treasure squares)	Rich	N	5 lessons/min. of 3 times	A: Accommodations for individualized needs	3	ID/OI (2); ID/OI/VI (1)	(1); 11 (2)
Huntington (1994)	Algebra lab gear	Bland	Y	5 days/wk (30)	A: Strategy inst. on PS	3	SLD (3)	15 (1); 17 (2)
Jimenez et al. (2008)	Wooden shapes, spoons, pens, pencils, paperclips, colored markers	Bland/ Rich	Y	NR	A: Task analysis, systematic prompting	3	Mod DD (3)	15-17 (3)
Jimenez & Kemmery (2013)	Theme counters (e.g. jewels, gold coins, cars, horses, money, plastic worms)	Rich	N	12 lessons	A: Task analysis, systematic prompting	5	ASD/Mod ID (2); Mod ID (3)	2nd gr (1); 3rd gr (2); 4th gr (2)
Jimenez & Staples (2015)	Theme counters (e.g. race cars)	Rich	Y	NR	—	3	Mod ID/HI (1); Mod ID (2)	10 (1); 11 (1)
Maccini & Hughes (2000)	Algebra lab gear	Bland	Y	NR	B: Edible rewards; A: Strategy inst. (STAR)	3	SLD (3)	14 (2); 15 (1)
Maccini & Ruhl (2000)	Colored titles	Bland	Y	NR	A: Strategy inst. (STAR)	6	SLD (6)	14 (1); 15 (2); 16 (2); 18 (1)
Mancl (2012)	NR	Bland	Y	17 (30)	B: Self-graphing, learning contract; Schema-based inst. strategy	3	SLD (3)	10 (2); 11 (1)
Mancl et al. (2012)	Base-ten block	—	Y	11 (30)	Inst. strategy (RENAME)	5	SLD (5)	10 (4); 11 (1)
Marsh & Cooke (1996)	Cuisenaire rods	Bland	N	4–12 (20)		3	SLD (3)	8 (1); 9 (1); 10 (1)

Miller & Mercer (1993)	Checkers, popsicle sticks, buttons, pennies, dimes	Bland/ Rich	Y	(20)	—	9	SLD (5); At-risk (3); EMH (1)	7 (1); 8 (3); 9 (2); 10 (1); 11 (2)
Morin & Miller (1998)	Paper plots, wooden blocks	Bland	Y	11 (35)	Strategy inst. (DRAW, FAST DRAW)	3	MR/VI (1); MR (1); MR/Phy (1)	15 (1); 16 (2)
Mulcahy & Krezmien (2009)	NR	—	N	11–13 (45)	B: Self-monitor academic perf. & beh.; A: Contextualized inst.	4	EBD (4)	11 (1); 12 (1); 14 (2)
Ok & Bryant (2016)	Connect cubes	Bland	Y	15 lessons		4	SLD (4)	10 (2): 11 (2)
Ozdemir (2018)	Pictures of objects[a]	Rich	VRA	(20)	—	3	OHI (1); ED (2)	8 (1); 9 (2)
Reneau (2013)	Fraction tiles[b]	Bland	Y	21 (30–40)	A: Schema strategy instr. (LISTS) modified	5	SLD (1); OHI (1); At-risk (3)	11 (3); 12 (2)
Root et al. (2017)	Colored counter[b]	Bland	N	Heuristic: 3 (15–20) Schema: (10–15)	A: Schema inst. strategy inst. prompt in chaining	3	ASD/Mod ID (3)	7 (1); 9 (1); 11 (1)
Satsangi & Bouck (2015)	Polynomial manipulatives[a]	Bland	N	8 wks	—	3	SLD (3)	14 (1); 16 (1); 18 (1)
Satsangi et al. (2016)	Balance, chips[a]	Bland	N	30 (15–20)	—	3	SLD (3)	17 (1); 18 (1); 19 (1)
Satsangi, Hammer, & Evmenova (2018)	Balance, chips[a]	Bland	N	12 wks (60)	—	3	SLD (3)	14 (2); 16 (1)
Satsangi, Hammer, & Hogan (2018)	Balance, chips[a]	Bland	N	(20–30)	B: C&A	3	SLD (3)	15 (3)
Saunders (2014)	Counters[a]	Bland	N	8 lessons	A: CBVI schema-base inst,.	3	ASD/Mod ID (3)	7 (1); 8 (1); 11 (1)
Scheuermann et al. (2009)	Buttons, unifix cubes	Rich	Y	13–23 (55)	scaffolded inq.	14	SLD (14)	11 (1); 12 (3); 13 (7);

Sealander et al. (2012)	Manipulatives (generic)	—	Y	9 (15)	—	8	SLD (5); EBD (3)	6 (1); 7 (4); 8 (2)
Shin (2013)	Rectangular area model[a]	Bland	N	8 (30)	A: Cognitive Strategy (read, restate, represent, answer) problem structures	3		
Shin & Bryant (2017)	NR[a]	—	N	9–10 (20) 1 intro (30)	A: Metacognitive strategy inst.	3	SLD (3)	13 (1); 15 (2)
Strickland & Maccini (2013a)	Algebra lab gear	Bland	Y	3 targets (40) 9 lessons,	B: Token economy	3	SLD/OHI (1); SLD (2)	13 (1); 14 (1); 15 (1)
Strickland & Maccini (2013b)	Algebra lab gear	Bland	CRA-I	G1:10 (45) G2: 13 (45)	—	5	SLD (1); SLD/OHI (2); At-risk (2)	16 (4); 17 (1)
Stroizer et al. (2015)	Base ten blocks	Bland	Y	(20)	A: Strategy inst. (RENAME, DRAW)	3	ASD (3)	8 (1); 10 (2)
Yakubova et al. (2016)	NR	—	Y	23 days (30)	B: Checklist, self-recording; A: Video modeling	4	ASD (4)	5 (1); 6 (3)

Note. Studies used only concrete manipulatives unless otherwise marked. VRA = virtual-representational-abstract framework.

[a]Virtual manipulatives. [b]Virtual and concrete manipulatives.

Appendix C

Visual Analysis Results

Study	OE 1	OE 2	OE 3	OE 4	FR
Agrawal (2013, study 1)					
Conceptual	2	2	2	2	2
Procedural	2	2	2	2	2
Agrawal (2013, study 2)					
Conceptual	2	2	2	2	2
Procedural	2	2	2	2	2
Bouck, Bassette, et al. (2017)	2	1	2	2	1
Bouck, Park, & Nickell (2017)	2	2	2	2	2
Bouck, Park, et al. (2017)	2	1	2	1	1
Bouck et al. (2018)					
Adam	2	1	2	2	1
Zane	2	1	2	2	1
Browder, Jimenez, Spooner, et al. (2012)					
Figure 3	2	2	2	1	1
Figure 4	2	1	2	1	1
Figure 5	2	1	2	2	1
Figure 6	2	1	2	2	1
Browder et al. (2018)	2	0	2	2	0
Burns et al. (2015)	2	1	0	0	0
Cass et al. (2003)					
Area	2	2	2	2	2
Perimeter	2	1	2	2	1
Cihak & Grim (2008)					
Figure 1	2	2	2	2	2
Figure 2	2	2	2	2	2
Figure 3	2	2	2	2	2
Figure 4	2	2	2	2	2
Denny & Test (1995)	2	0	0	0	0
Flores (2009)	2	1	2	2	1
Flores (2010)					
Figure 5	2	1	2	2	1
Figure 6	2	1	2	2	1

Flores, Hinton, & Schweck (2014)					
Figure 3	2	2	2	2	2
Figure 4	2	2	2	2	2
Figure 5	2	2	2	2	2
Flores, Hinton, & Strozier (2014)	2	2	2	2	2
Flores, Hinton, & Burton (2016)	2	2	2	2	2
Hardy (2014)					
Figure 3	2	1	2	2	1
Figure 4	2	1	0	0	0
Figure 5	2	1	2	2	1
Harris et al. (1995)					
Figures 1–3	2	1	0	0	0
Figures 4–6	2	1	0	0	0
Hinton et al. (2016)					
Figure 1	2	1	2	2	1
Figure 2	2	1	2	2	1
Figure 3	2	1	2	2	1
Figure 4	2	1	2	2	1
Hord & Xin (2015)	0	0	0	0	0
Hudson et al. (2016)	2	0	2	2	0
Huntington (1994)					
Representation	2	1	0	0	0
Solution	2	1	0	0	0
Jiminez et al. (2008)	2	1	2	2	1
Jiminez & Kemmery (2013)	1	1	0	0	0
Jiminez & Staples (2015)	1	2	2	2	1
Maccini & Hughes (2000)					
Representation	1	0	0	0	0
Solution	0	0	0	0	0
Maccini & Ruhl (2000)					
Figure 2 – Representation	1	0	2	2	0
Figure 2 – Solution	0	0	0	0	0
Figure 3 – Representation	1	0	2	2	0
Figure 3 – Solution	1	0	0	0	0
Figure 4 – Representation	2	0	2	2	0

Figure 4 – Solution	1	0	2	2	0
Figure 5 – Representation	2	0	2	2	0
Figure 5 – Solution	2	0	2	2	0
Figure 6 – Representation	2	0	2	2	0
Figure 6 – Solution	0	0	0	0	0
Figure 7 – Representation	2	0	0	0	0
Figure 7 – Solution	1	0	0	0	0
Figure 8 – Representation	2	0	2	2	0
Figure 8 – Solution	1	0	0	0	0
Figure 9 – Representation	2	0	0	0	0
Figure 9 – Solution	1	0	0	0	0
Mancl (2012)	1	1	0	0	0
Mancl et al. (2012)	2	1	2	1	1
Miller & Mercer (1993)					
Figure 1	1	2	0	0	0
Figure 2	1	1	0	0	0
Figure 3	2	2	0	0	0
Morin & Miller (1998)	1	1	2	2	1
Mulcahy & Krezmien (2009)					
Figure 1	2	0	0	0	0
Figure 2	2	0	0	0	0
Ok & Bryant (2015)	2	1	2	2	1
Ozdemir (2018)	2	1	2	2	1
Reneau (2013)	1	1	2	0	0
Root et al. (2017)					
Concrete	2	0	2	2	0
Virtual	2	0	2	2	0
Satsangi & Bouck (2015)					
Area	2	2	2	2	2
Perimeter	2	2	2	2	2
Satsangi, Hammer, & Evmenova (2018)	2	2	2	2	2
Satsangi, Hammer, & Hogan (2018)	2	2	2	2	2
Saunders (2014)	2	1	2	2	1
Scheuermann et al. (2009)					
Figure 2	2	1	2	2	1

Figure 3	1	1	2	2	1
Figure 4	2	1	2	2	1
Figure 5	1	1	2	2	1
Sealander et al. (2012)					
Figure 1	2	1	0	0	0
Figure 2	1	1	0	0	0
Figure 3	2	1	0	0	0
Shin & Bryant (2017)	1	1	2	2	1
Strickland & Maccini (2013a)	2	0	2	2	0
Strickland & Maccini (2013b)	2	0	2	2	0
Stroizer et al. (2015)					
Figure 1	2	0	2	2	1
Figure 2	2	1	2	2	1
Figure 3	2	1	2	2	1
Yakubova et al. (2016)					
Figure 1	2	2	2	2	2
Figure 2	1	2	2	2	1
Figure 3	1	2	2	2	1
Figure 4	1	2	2	2	1

Note. OE 1 refers to the quality of baseline data, OE 2 refers to the quantity of data points per phase, OE 3 refers to determining if three presentations of treatment effect are evidence, OE 4 refers to determining the ratio of responders to nonresponders, FR = final ranking.

Appendix D

What Works Clearing House Quality Indicator Coding

Title	DS 1	DS 2a	DS 2b	DS 2c	DS 3	DS 4	DS 5a	DS 5b	DS 5c	OE
					Multiple baseline design					
Agrawal (2013, study 1)	1	1	2	2	1	2	—	—	—	2
Agrawal (2013, study 2)	1	1	2	2	1	2	—	—	—	2
Burns et al. (2015)	1	1	1	1	1	1	—	—	—	1
Denny & Test (1995)	1	1	1	1	1	0	—	—	—	0
Harris et al. (1995)	1	1	2	2	1	0	—	—	—	0
Marsh & Cooke (1996)	1	0	0	0	1	1	—	—	—	0
Miller & Mercer (1993)	1	0	0	0	1	1	—	—	—	0
Morin & Miller (1998)	1	1	2	2	1	1	—	—		1
Ozdemir (2018)	1	1	1	1	1	1	—	—	—	1
Reneau (2013)	1	1	2	2	1	1	—	—	—	1
Satsangi & Bouck (2015)	1	1	2	2	1	2	—	—	—	2
Satsangi, Hammer, & Evmenova (2018)	1	1	2	2	1	2	—	—	—	2
Satsangi, Hammer, & Hogan (2018)	1	1	2	2	1	2	—	—	—	2
Sealander et al. (2012)	1	1	2	1	1	1	—	—	—	1
Stroizer et al. (2015)	1	1	1	1	1	1	—	—	—	1
Yakubova et al. (2016)	1	1	2	2	1	2	—	—	—	2
					Multiple probe design					
Bouck, Bassette, et al. (2017)	1	1	2	2	1	1	2	1	0	1
Bouck, Park, & Nickell (2017)	1	1	2	2	1	1	2	0	0	2
Bouck, Park, et al. (2017)	1	1	2	2	1	1	2	1	1	1
Browder, Jimenez, Spooner, et al. (2012)	1	1	1	1	1	1	2	0	0	1
Browder et al. (2018)	1	1	2	2	1	0	2	2	0	0

Cass et al. (2003)	1	1	1	1	1	1	2	0	0	1
Cihak & Grim (2008)	1	1	2	2	1	2	2	1	0	2
Flores (2009)	1	1	1	1	1	1	1	0	0	1
Flores (2010)	1	1	1	1	1	1	1	0	0	1
Flores, Hinton, & Schweck (2014)	1	1	1	1	1	1	1	0	0	1
Flores, Hinton, & Strozier (2014)	1	1	2	1	1	2	2	0	0	1
Flores, Hinton, & Burton (2016)	1	1	0	2	1	2	2	0	1	0
Hardy (2014)	1	1	2	2	1	1	2	1	0	1
Hinton et al. (2016)	1	1	2	2	1	1	1	0	0	1
Hord & Xin (2015)	1	1	1	2	1	1	1	0	0	1
Hudson et al. (2016)	1	1	2	2	1	0	2	1	0	0
Huntington (1994)	1	1	2	1	1	1	1	2	0	1
Jiminez et al. (2008)	1	1	1	1	1	1	2	1	0	1
Jiminez & Kemmery (2013)	1	1	2	2	1	1	2	1	0	1
Jiminez & Staples (2015)	1	1	2	2	1	2	2	0	0	2
Maccini & Hughes (2000)	1	1	1	1	1	0	1	1	0	0
Maccini & Ruhl (2000)	1	1	1	1	1	0	1	1	0	0
Mancl (2012)	1	1	2	2	1	1	2	1	0	1
Mulcahy & Krezmien (2009)	1	1	2	2	0	0	1	1	0	0
Ok & Bryant (2015)	1	1	2	1	1	1	2	1	0	1
Root (2017) (c)	1	1	2	2	1	0	0	0	0	0
Root (2017) (v)	1	1	2	2	1	0	0	0	0	0
Satsangi, Hammer, & Hogan (2018)	1	1	2	1	1	2	1	0	0	2
Saunders (2014)	1	1	2	2	1	2	2	2	0	2
Scheuermann et al. (2009)	1	1	1	1	1	0	2	2	1	0
Shin & Bryant (2017)	1	1	2	2	1	1	1	1	1	1
Strickland & Maccini (2013a)	1	1	1	1	1	0	1	1	0	0

Strickland & Maccini (2013b)	1	1	1	1	1	0	1	1	0	0

Note. DS = Design Standard; OE = Overall Evaluation.

Appendix E

Studies Included in the Meta-Analysis

Agrawal, J. (2013). *The effects of explicit instruction with manipulatives on the fraction skills of students with autism* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Global (Accession No. 1371024436)

Bouck, E. C., Bassette, L., Shurr, J., Park, J., Kerr, J., & Whorley, A. (2017). Teaching equivalent fractions to secondary students with disabilities via the virtual–representational–abstract instructional sequence. *Journal of Special Education Technology*, *32*, 220-231. doi:10.1177/0162643417727291

Bouck, E. C., Chamberlain, C., & Park, J. (2017). Concrete and app-based manipulatives to support students with disabilities with subtraction. *Education and Training in Autism and Developmental Disabilities*, *52*, 317-331.

Bouck, E., Park, J., & Nickell, B. (2017). Using the concrete-representational-abstract approach to support students with intellectual disability to solve change-making problems. *Research in Developmental Disabilities*, *60*, 24-36. doi:10.1016/j.ridd.2016.11.006

Bouck, E. C., Park, J., Shurr, J., Bassette, L., & Whorley, A. (2018). Using the virtual–representational–abstract approach to support students with intellectual disability in mathematics. *Focus on Autism and Other Developmental Disabilities*, *33*, 237-248. doi:10.1177/1088357618755696

Bouck, E. C., Park, J., Sprick, J., Shurr, J., Bassette, L., & Whorley, A. (2017). Using the virtual-abstract instructional sequence to teach addition of fractions. *Research in Developmental Disabilities*, *70*, 163-174. doi:10.1016/j.ridd.2017.09.002

Bouck, E. C., Satsangi, R., Doughty, T. T., & Courtney, W. T. (2014). Virtual and concrete manipulatives: A comparison of approaches for solving mathematics problems for students with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *44*, 180-193. doi:10.1007/s10803-013-1863-2

Browder, D. M., Jimenez, B. A., Spooner, F., Saunders, A., Hudson, M., & Bethune, K. S. (2012). Early numeracy instruction for students with moderate and severe developmental disabilities. *Research and Practice for Persons with Severe Disabilities*, *37*, 308-320. doi:10.2511/027494813805327205

Browder, D. M., Jimenez, B. A., & Trela, K. (2012). Grade-aligned math instruction for secondary students with moderate intellectual disability. *Education and Training in Autism and Developmental Disabilities*, *47,* 373-388.

Browder, D. M., Spooner, F., Lo, Y. Y., Saunders, A. F., Root, J. R., Davis, L. L., & Brosh, C. R. (2018). Teaching students with moderate intellectual disability to solve word problems. *The Journal of Special Education*, *51,* 222-235. doi:10.11770022466917721236

Burns, M. K., Walick, C., Simonson, G. R., Dominguez, L., Harelstad, L., Kincaid, A., & Nelson, G. S. (2015). Using a conceptual understanding and procedural fluency heuristic to target math interventions with students in early elementary. *Learning Disabilities Research & Practice*, *30,* 52-60. doi:10.1111/ldrp.12056

Cass, M., Cates, D., Smith, M., & Jackson, C. (2003). Effects of manipulative instruction on solving area and perimeter problems by students with learning disabilities. *Learning Disabilities Research & Practice*, *18*, 112-120. doi:10.1111/1540-5826.000067

Cihak, D. F., & Grim, J. (2008). Teaching students with autism spectrum disorder and moderate intellectual disabilities to use counting-on strategies to enhance independent purchasing skills. *Research in Autism Spectrum Disorders*, *2*, 716-727. doi:10.1016/j.rasd.2008.02.006

Denny, P. J., & Test, D. W. (1995). Using the one-more-than technique to teach money counting to individuals with moderate mental retardation: A systematic replication. *Education and Treatment of Children*, *18,* 422-432.

Flores, M. M. (2009). Teaching subtraction with regrouping to students experiencing difficulty in mathematics. *Preventing School Failure: Alternative Education for Children and Youth*, *53,* 145-152. doi:10.3200/PSFL.53.3.145-152

Flores, M. M. (2010). Using the concrete-representational-abstract sequence to teach subtraction with regrouping to students at risk for failure. *Remedial and Special Education*, *31,* 195-207. doi:10.1177/0741932508327467

Flores, M. M., Hinton, V. M., & Burton, M. E. (2016). Teaching problem solving to students receiving tiered interventions using the concrete-representational-abstract sequence and schema-based instruction. *Preventing School Failure: Alternative Education for Children and Youth*, *60,* 345-355. doi:10.1080/1045988X.2016.1164117

Flores, M. M., Hinton, V. M., & Schweck, K. B. (2014). Teaching multiplication with regrouping to students with learning disabilities. *Learning Disabilities Research & Practice*, *29*, 171-183. doi:10.1111/ldrp.12043

Flores, M. M., Hinton, V., & Strozier, S. D. (2014). Teaching subtraction and multiplication with regrouping using the concrete-representational-abstract sequence and strategic instruction model. *Learning Disabilities Research & Practice*, *29*, 75-88. doi:10.1111/ldrp.12032

Hardy, J. K. (2014). *Systematic Instruction of Early Math Skills* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Global (Accession No. 1556628957).

Harris, C. A., Miller, S. P., & Mercer, C. D. (1995). Teaching initial multiplication skills to students with disabilities in general education classrooms. *Learning Disabilities Research & Practice, 10*, 180-195.

Hinton, V. M., Flores, M. M., Schweck, K., & Burton, M. E. (2016). The effects of a supplemental explicit counting intervention for preschool children. *Preventing School Failure: Alternative Education for Children and Youth*, *60*, 183-193. doi:10.1080/1045988X.2015.1065400

Hord, C., & Xin, Y. P. (2015). Teaching area and volume to students with mild intellectual disability. *The Journal of Special Education*, *49*, 118-128. doi:10.1177/002246914527829

Hudson, M. E., Zambone, A., & Brickhouse, J. (2016). Teaching early numeracy skills using single switch voice-output devices to students with severe multiple disabilities. *Journal of Developmental and Physical Disabilities, 28*, 153-175. doi:10.1007/s10882-015-9451-3

Huntington, D. J. (1994). *Instruction in concrete, semi-concrete, and abstract representation as an aid to the solution of relational problems by adolescents with learning disabilities* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Global (Accession No. 304084774)

Jimenez, B. A., Courtade, G. R., & Browder, D. M. (2008). Teaching an algebraic equation to high school students with moderate developmental disabilities. *Education and Training in Developmental Disabilities*, *43*, 266-274.

Jimenez, B. A., & Kemmery, M. (2013). Building the early numeracy skills of students with moderate intellectual disability. *Education and Training in Autism and Developmental Disabilities, 48*, 479-490.

Jimenez, B. A., & Staples, K. (2015). Access to the common core state standards in mathematics through early numeracy skill building for students with significant intellectual disability. *Education and Training in Autism and Developmental Disabilities*, *50*, 17-30.

Maccini, P., & Hughes, C. A. (2000). Effects of a problem-solving strategy on the introductory algebra performance of secondary students with learning disabilities. *Learning Disabilities Research & Practice*, *15,* 10-21. doi:10.1207/sldrp1501_2

Maccini, P., & Ruhl, K. L. (2000). Effects of a graduated instructional sequence on the algebraic subtraction of integers by secondary students with learning disabilities. *Education and Treatment of Children*, *23,* 465-489.

Mancl, D. B. (2011). *Investigating the effects of a combined problem-solving strategy for students with learning difficulties in mathematics* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Global (Accession No. 876194235).

Mancl, D. B., Miller, S. P., & Kennedy, M. (2012). Using the concrete-representational-abstract sequence with integrated strategy instruction to teach subtraction with regrouping to students with learning disabilities. *Learning Disabilities Research & Practice*, *27,* 152-166. doi:10.1111/j.1540-5826.2012.00363.x

Marsh, L. G., & Cooke, N. L. (1996). The effects of using manipulatives in teaching math problem solving to students with learning disabilities. *Learning Disabilities Research and Practice*, *11,* 58-65.

Miller, S. P., & Mercer, C. D. (1993). Using data to learn concrete-semiconcrete-abstract instruction for students with math disabilities. *Learning Disabilities Research & Practice*, *8,* 89-96.

Morin, V. A., & Miller, S. P. (1998). Teaching multiplication to middle school students with mental retardation. *Education and Treatment of Children*, *21,* 22-36.

Mulcahy, C. A., & Krezmien, M. P. (2009). Effects of a contextualized instructional package on the mathematics performance of secondary students with EBD. *Behavioral Disorders*, *34,* 136-150.

Ok, M. W., & Bryant, D. P. (2016). Effects of a strategic intervention with iPad practice on the multiplication fact performance of fifth-grade students with learning disabilities. *Learning Disability Quarterly*, *39,* 146-158. doi:10.1177/0731948715598285

Ozdemir, R. (2017). *The investigation of virtual concrete-representational-abstract model to teach one digit multiplication word problem to students with emotional and behavioral disorders* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Global (Accession No. 1926728075).

Reneau, J. L. (2012). *Using the concrete-representational-abstract sequence to connect manipulatives, problem solving schemas, and equations in word problems with fractions* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Global (Accession No. 1095130428).

Root, J. R., Browder, D. M., Saunders, A. F., & Lo, Y. Y. (2017). Schema-based instruction with concrete and virtual manipulatives to teach problem solving to students with autism. *Remedial and Special Education*, *38,* 42-52. doi:10.1177/0741932516643592

Satsangi, R., & Bouck, E. C. (2015). Using virtual manipulative instruction to teach the concepts of area and perimeter to secondary students with learning disabilities. *Learning Disability Quarterly, 38,* 174-186. doi:10.1177/0731948714550101

Satsangi, R., Bouck, E. C., Taber-Doughty, T., Bofferding, L., & Roberts, C. A. (2016). Comparing the effectiveness of virtual and concrete manipulatives to teach algebra to secondary students with learning disabilities. *Learning Disability Quarterly, 39,* 240-253. doi:10.1177/0731948716649754

Satsangi, R., Hammer, R., & Evmenova, A. S. (2018). Teaching multistep equations with virtual manipulatives to secondary students with learning disabilities. *Learning Disabilities Research & Practice*, *33,* 99-111. doi:10.1111/ldrp.12166

Satsangi, R., Hammer, R., & Hogan, C. D. (2018). Studying virtual manipulatives paired with explicit instruction to teach algebraic equations to students with learning disabilities. *Learning Disability Quarterly, 41,* 227-242. doi:10.1177/0731948718769248

Saunders, A. F. (2014). *Effects of schema-based instruction delivered through computer-based video instruction on mathematical word problem solving students with autism spectrum disorder and moderate intellectual disability* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Global (Accession No. 1615426003).

Scheuermann, A. M., Deshler, D. D., & Schumaker, J. B. (2009). The effects of the explicit inquiry routine on the performance of students with learning disabilities on one-variable equations. *Learning Disability Quarterly*, *32,* 103-120. doi:10.2307/27740360

Sealander, K. A., Johnson, G. R., Lockwood, A. B., & Medina, C. M. (2012). Concrete–semiconcrete–abstract (CSA) instruction: A decision rule for improving instructional efficacy. *Assessment for Effective Intervention*, *38,* 53-65. doi:10.1177/1534508412453164

Shin, M., & Bryant, D. P. (2017). Improving the fraction word problem solving of students with mathematics learning disabilities: Interactive computer application. *Remedial and Special Education*, *38,* 76-86. doi:10.1177/0741932516669052

Strickland, T. K., & Maccini, P. (2013). Exploration of quadratic expressions through multiple representations for students with mathematics difficulties. *Learning Disabilities: A Multidisciplinary Journal*, *19,* 61-71.

Strickland, T. K., & Maccini, P. (2013). The effects of the concrete–representational–abstract integration strategy on the ability of students with learning disabilities to multiply linear expressions within area problems. *Remedial and Special Education*, *34,* 142-153. doi:10.1177/0741932512441712

Stroizer, S., Hinton, V., Flores, M., & Terry, L. (2015). An investigation of the effects of CRA instruction and students with autism spectrum disorder. *Education and Training in Autism and Developmental Disabilities*, *50,* 223-236.

Yakubova, G., Hughes, E. M., & Shinaberry, M. (2016). Learning with technology: Video modeling with concrete–representational–abstract sequencing for students with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *46,* 2349-2362. doi:10.1007/s10803-016-2768-7