Multimedia Effect in Problem Solving: A Meta-Analysis

UIUC
Oct. 18, 2019

Liru Hu, Gaowei Chen, Pengfei Li, Jing Huang

Which one is better?

A full water tank on a water dispenser contains 20 liter.
Students from the dispenser fill their 25 cl water bottles.

How many water bottles can be filled from a full water tank?

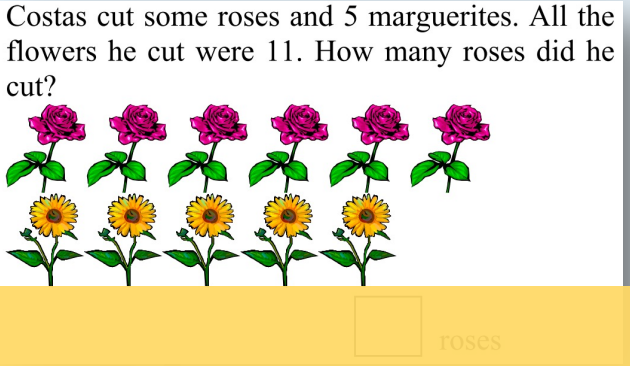
☐ **bottles**

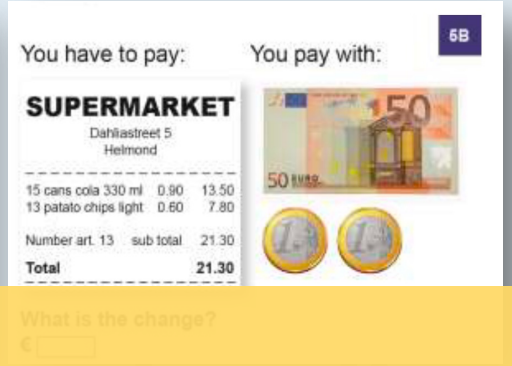
How many water bottles can be filled from a full water tank?

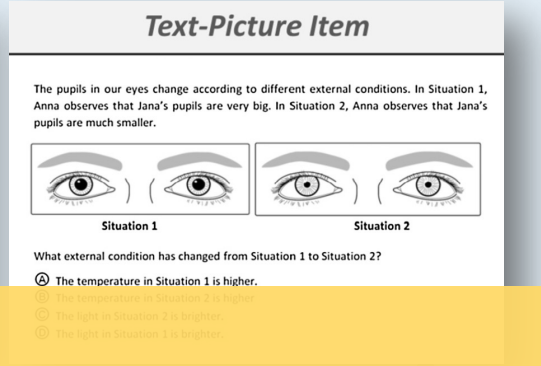
☐ **bottles**

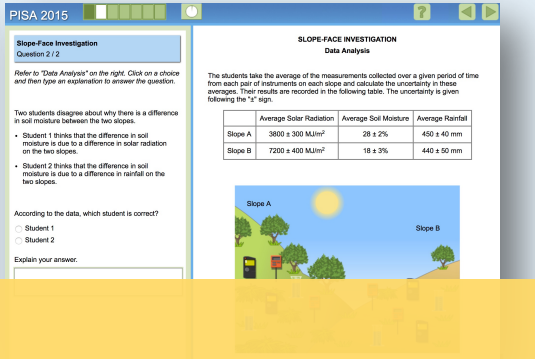
Actually,

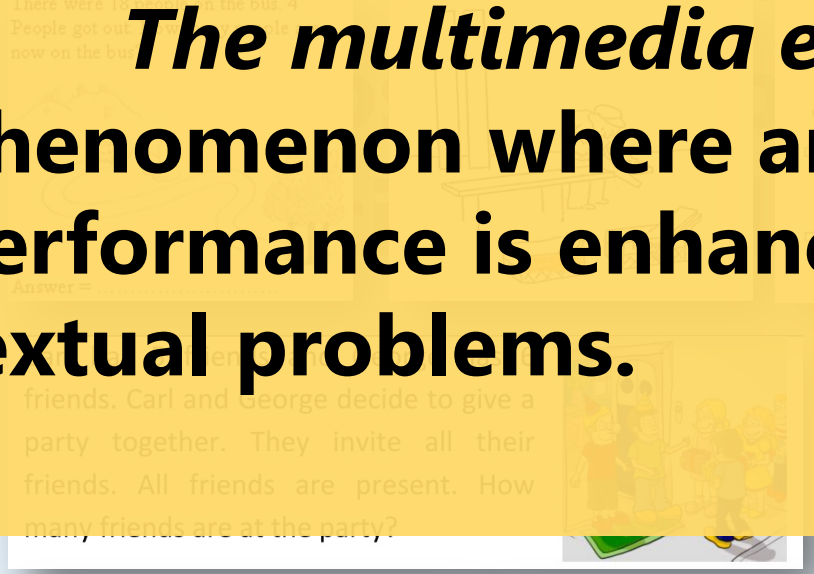
Pictures, graphs, diagrams, animations and videos have been very common on usual exercises and standardized tests.

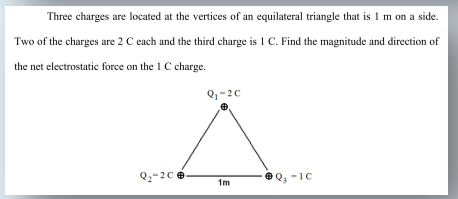


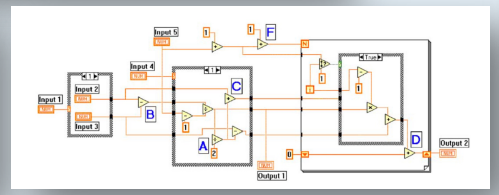


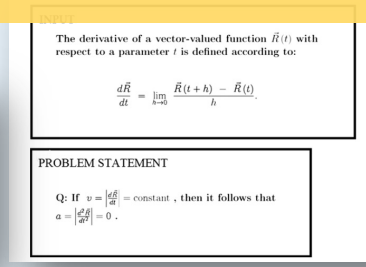


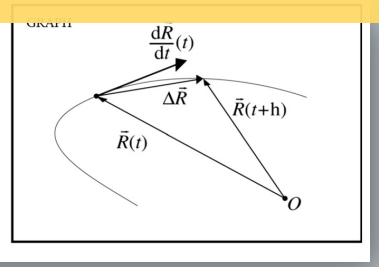


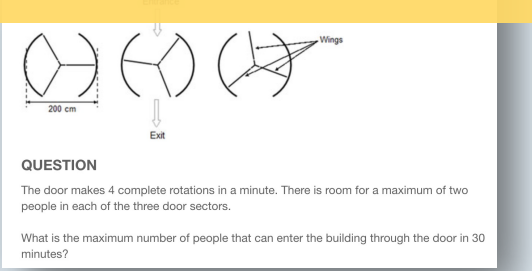






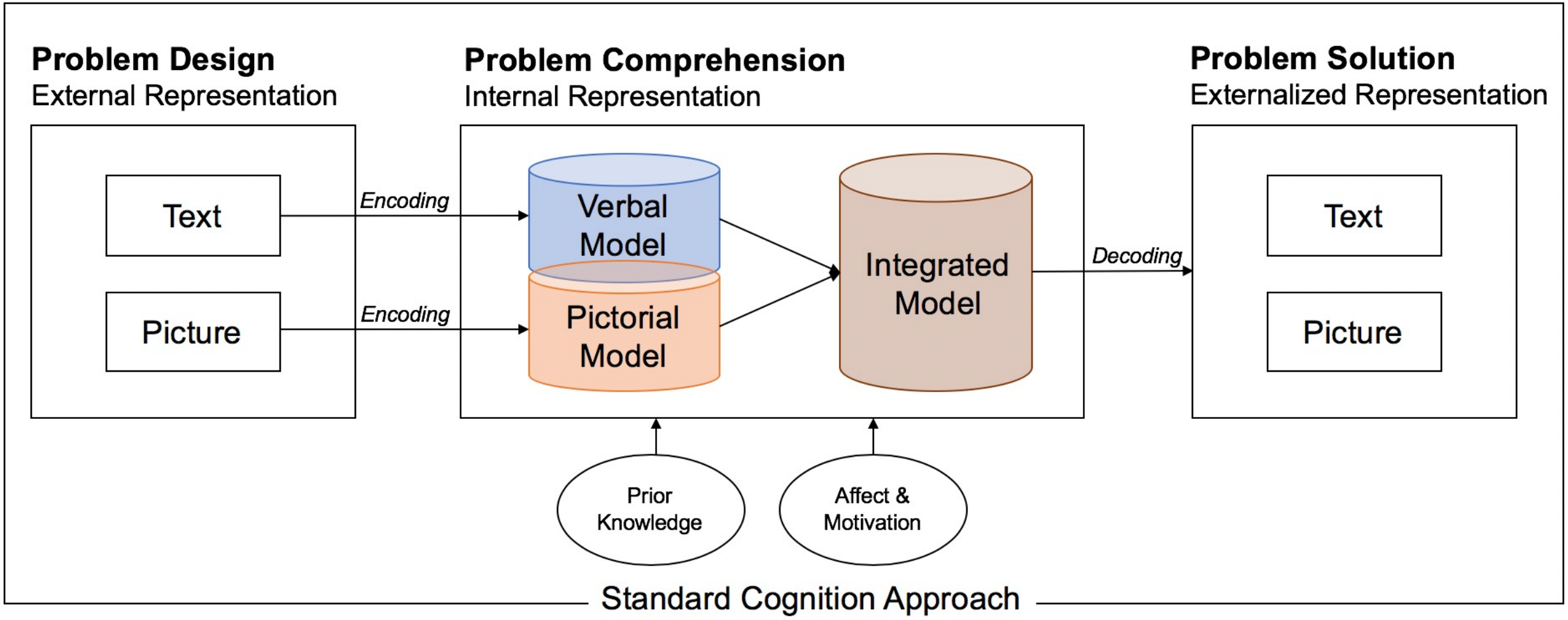






The multimedia effect in problem solving **describes the phenomenon where an individual's problem-solving performance is enhanced when pictures are added to textual problems.**

Theoretical Background



Literature Review

Lindner, Lüdtke, Grund, & Köller, 2017; Whitley, Novick, & Fisher, 2006

Lindner, Eitel, Strobel, & Köller, 2017; Saß, Wittwer, Senkbeil, & Köller, 2012; Ögren, Nyström, & Jarodzka, 2017

Berends & van Lieshout, 2009

Lindner et al., 2017; Wise, Pastor, & Kong, 2009; Ögren, Nyström, & Jarodzka, 2017 ; Hao, 2010; Lindner et al., 2016; Bjork, Dunlosky, & Kornell, 2013

No comprehensive meta-analytic review has been conducted to determine the aggregated effect and its relevant boundary conditions.

Moderators

Function types of pictures(Agathangelou et al., 2008; Carney & Levin, 2002; Elia et al., 2007; Elia & Philippou, 2004; Gagatsis & Elia, 2004; Lindner et al., 2016, 2018).

- Informational
- Decorative
- Representational
- Organisational

Informational

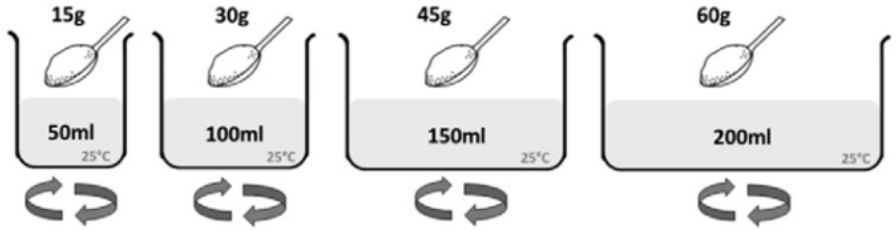
1B

About how many apples are there in the bag?

☐ **apples**

An informational picture in Math (Hoogland, de Koning, Bakker, Pepin, & Gravemeijer, 2018)

Maria designed an experiment using salt and water. She experienced that 15g salt dissolved in 50ml water, 30g salt in 100ml water, 45g salt in 150ml water and 60g salt in 200ml water. The water's temperature was always 25°C. Maria stirred every mixture several times.



What was Maria studying in her experiment?

Ⓐ How much salt will dissolve in different volumes of water.
Ⓑ How much salt will dissolve at different temperatures.
Ⓒ If stirring increases how fast salt
Ⓓ If stirring decreases how fast salt

A representational picture

Representational

Susie stands in front of a floodlight.

Where is her shadow?

Multip
Rep
C

Multiple

Carl has 5 friends and George has 6 friends. Carl and George decide to give a party together. They invite all their friends. All friends are present. How many friends are at the party?

Decorative

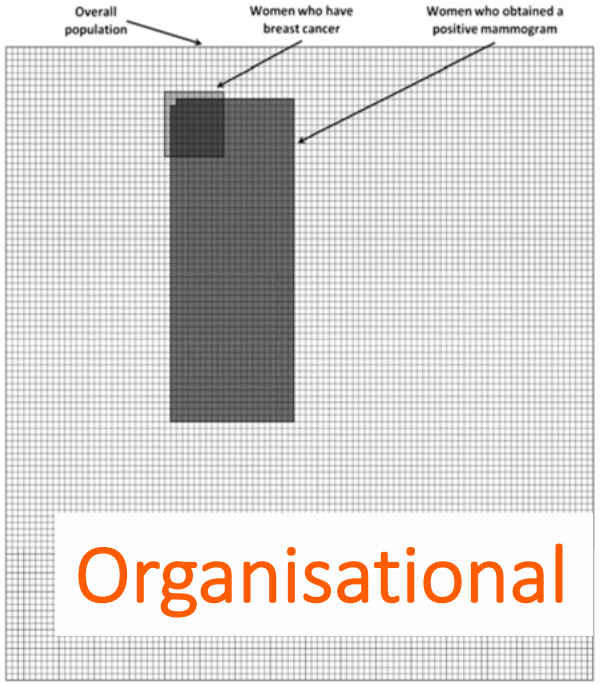
A decorative pictures in Math
(Dewolf, Van Dooren, Hermens, & Verschaffel, 2015)

Information about prevalence of the diseases, and sensitivity and false-positive rate of the tests provided in the probability (first line) and natural frequency (second line) conditions. Note that the false-positive rate is the complement of the specificity.

Diagnostic task	Base rate	Sensitivity	False-positive rate	Positive predictive value
Breast cancer	1% 100 of 10,000	80% 80 of 100	10% 990 of 9900	7% 80 of 1070

Imagine a representative sample of women who got a positive result on the mammography. Give your best guess: how many of these women do you expect to have breast cancer?

An organizational pictures in Medical Science
(Garcia-retamero & Hoffrage, 2013)



Organisational

Moderators

Problem complexity (Hoogland, Pepin, de Koning, Bakker, & Gravemeijer, 2018; Lindner et al., 2016; Solano-Flores, Wang, & Shade, 2016; Zahner & Corter, 2010)

- Pictures are more helpful in wordy/difficult problems

Research hypotheses

H1 Multimedia Effect on Response Accuracy

H2 Multimedia Effect on Response Time

H3 Multimedia Effect on Response Certainty

H4 Moderators

- Picture function
- Problem difficulty

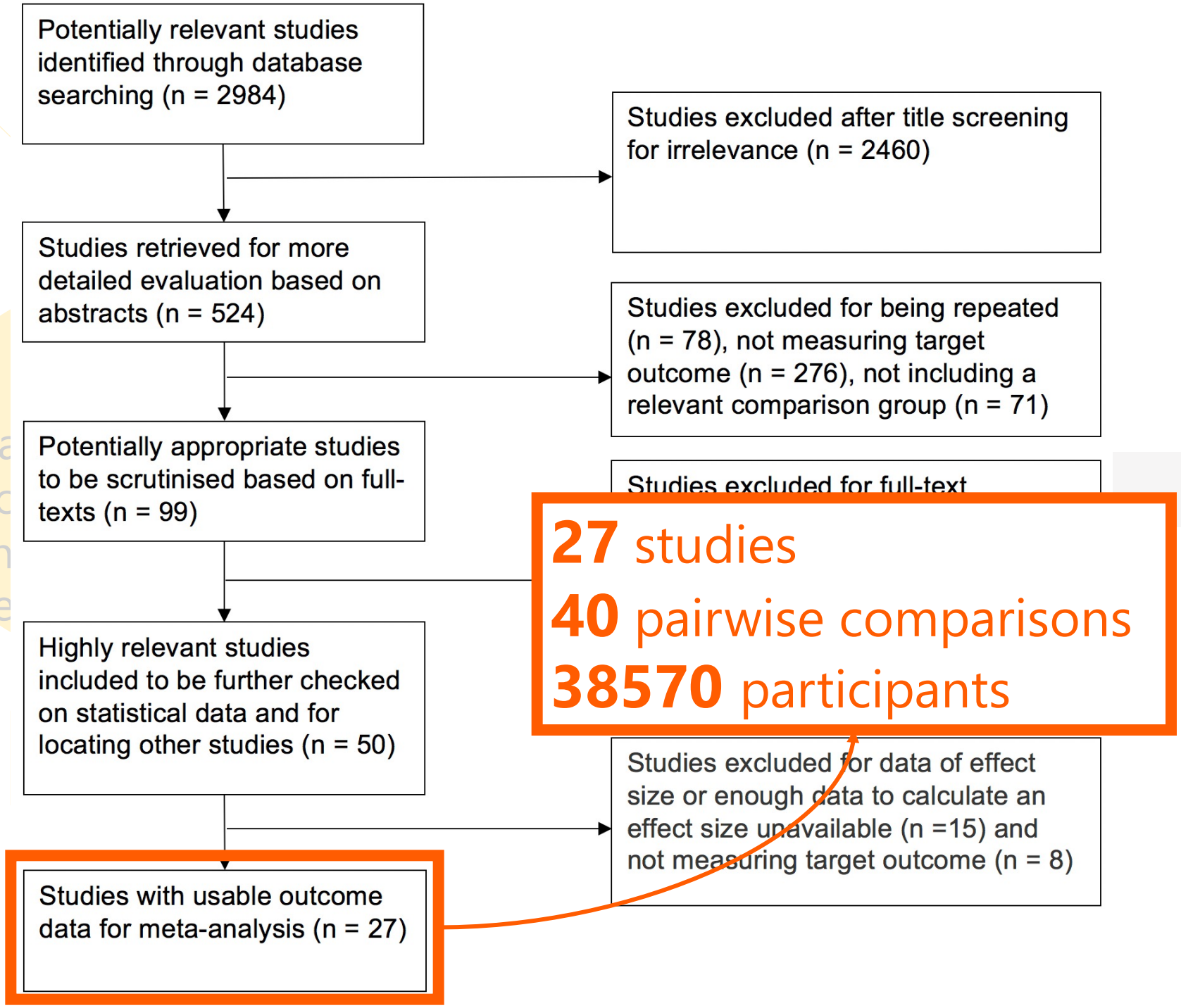
Method

Data Collection and Reduction

Coding Procedure

Computation of Effect Size

01 PRISMA


Potentially relevant studies identified through database searching (n = 2984)
Studies excluded after title screening for irrelevance (n = 2460)
Studies retrieved for more detailed evaluation based on abstracts (n = 524)
Studies excluded for being repeated (n = 78), not measuring target outcome (n = 276), not including a relevant comparison group (n = 71)
Potentially appropriate studies to be scrutinised based on full-texts (n = 99)
Studies excluded for full-text
27 studies
40 pairwise comparisons
38570 participants
Highly relevant studies included to be further checked on statistical data and for locating other studies (n = 50)
Studies excluded for data of effect size or enough data to calculate an effect size unavailable (n =15) and not measuring target outcome (n = 8)
Studies with usable outcome data for meta-analysis (n = 27)

Method

Data Collection and Reduction

Coding Procedure

Computation of Effect Size

01

PRISMA
27 studies
40 pairwise comparisons
38570 participants

02

Two independent coders
Moderators
Effect size

Method

Data Collection and Reduction

Coding Procedure

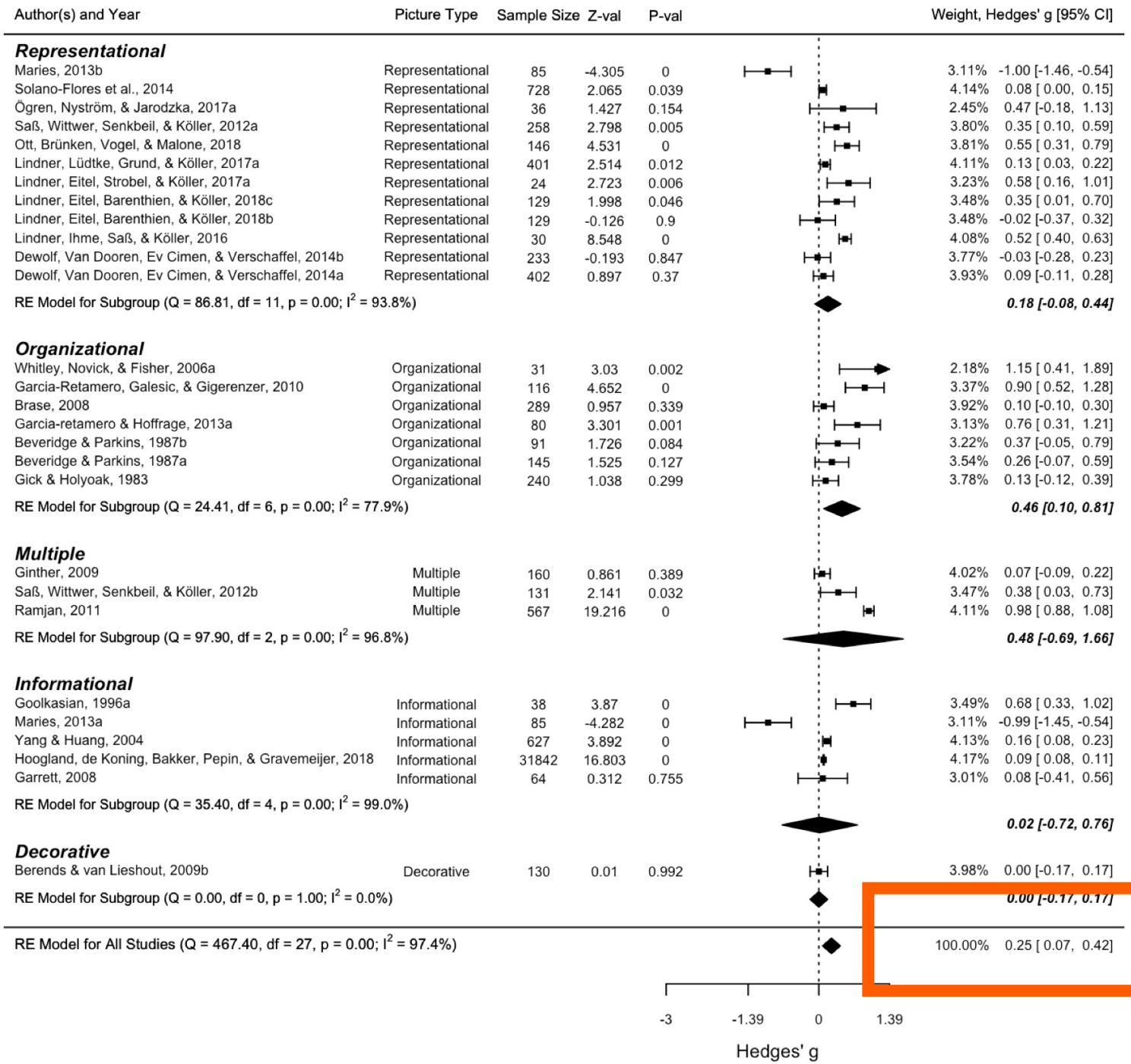
Computation of Effect Size

01
PRISMA
27 studies
40 pairwise comparisons
38570 participants

02
Two independent coders
Moderators
Effect size

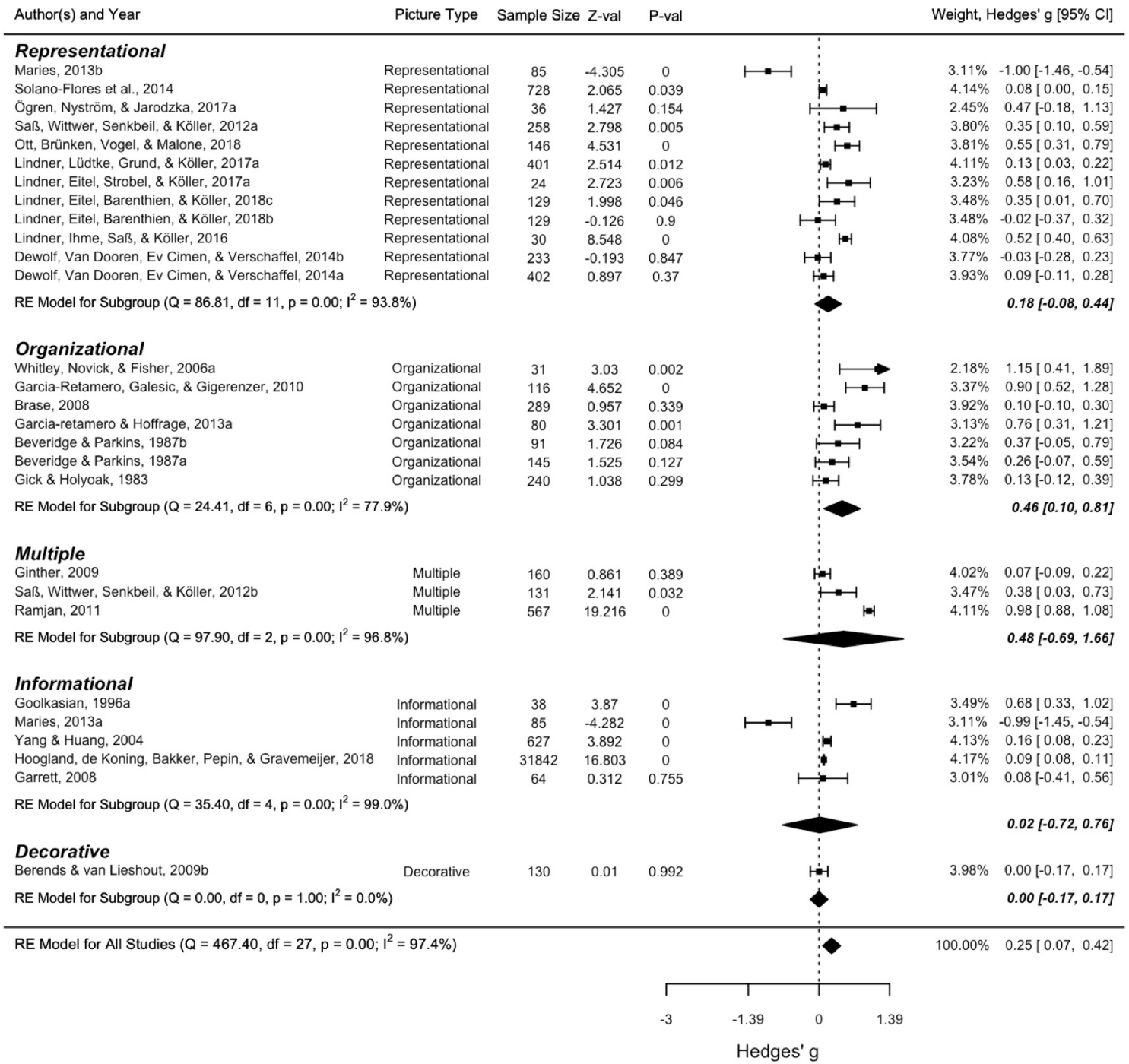
03
Metafor package in R
Publication Bias
Outlier analysis

Results



Hedges' g = 0.25

p = 0.01



Function type of picture is a significant moderator

- **Organisational** (Hedges' g = 0.46, p = 0.00)
- **Representational** (Hedges' g = 0.18, p = 0.15)
- **Informational** (Hedges' g = 0.02, p = 0.95) and
- **Decorative** (Hedges' g = 0.00, p = 1.00)
- **Multiple** (Hedges' g = 0.48, p = 0.00)

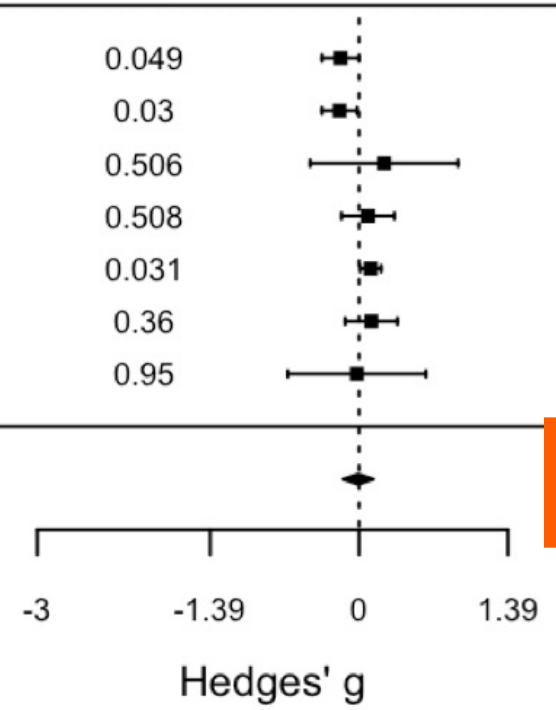
Possible Moderators	Q	I^2	p-value	k	Effect size (Hedges' g)	95% CI for Hedges' g
[illegible]				2		
Problem difficulty**	248.93	96.24 %		1		
(1) Easy			0.124	4	0.27	[-0.09, 0.63]
(2) Difficult	34.05	79.91 %	0.005**	1 4	0.17	[0.06, 0.27]
Domain						
(1) Science	107.81	95.67 %	0.300	1 4	0.16	[-0.15, 0.46]
(2) Math	327.42	97.65 %	0.030*	9	0.32	[0.04, 0.60]
(3) Medicine	17.38	85.71 %	0.160	3	0.56	[-0.54, 1.65]
(4) Language	0.00	0.00 %	0.020*	2	0.07	[0.03, 0.10]
Answer format**						
(1) Multiple-choice	66.62	83.86 %	0.000***	1 3	0.31	[0.17, 0.44]
(2) Structured open response	380.71	97.96 %	0.250	1 5	0.18	[-0.15, 0.51]
Testing environment***						
(1) Computer based	52.22	90.74 %	0.003**	1 2	0.36	[0.15, 0.56]
(2) Paper and pencil	338.00	96.99 %	0.269	1 6	0.15	[-0.12, 0.42]
Educational stage						
(1) Primary	46.25	78.72 %	0.005**	1 1	0.21	[0.08, 0.35]
(2) University	192.57	95.36 %	0.280	1 1	0.24	[-0.23, 0.70]
(3) Other	26.13	97.55 %	0.107	6 2	0.29	[-0.09,0.67]

Problem difficulty is also a significant moderator

- **Difficult** (Hedges' g = 0.17, p = 0.00),
- Easy: No effect

Results

Author(s) and Year	Picture Type	Sample Size	Z-val	P-val	Weight, Hedges' g [95% CI]
Berends & van Lieshout, 2009a	Decorative	130	-1.965	0.049	19.35% -0.17 [-0.34, -0.00]
Schwert, 2007	Informational	144	-2.174	0.03	19.99% -0.18 [-0.35, -0.02]
Whitley, Novick, & Fisher, 2006b	Organizational	31	0.665	0.506	3.19% 0.23 [-0.45, 0.92]
Lindner, Eitel, Strobel, & Köller, 2017b	Representational	62	0.662	0.508	14.30% 0.08 [-0.16, 0.33]
Lindner, Lüdtke, Grund, & Köller, 2017b	Representational	401	2.158	0.031	25.07% 0.11 [0.01, 0.21]
Saß, Wittwer, Senkbeil, & Köller, 2012	Representational	258	0.916	0.36	14.49% 0.11 [-0.13, 0.36]
Ögren, Nyström, & Jarodzka, 2017b	Representational	36	-0.063	0.95	3.60% -0.02 [-0.66, 0.62]
RE Model for All Studies (Q = 14.87, df = 6, p = 0.02; I^2 = 58.9%)					100.00% -0.01 [-0.15, 0.13]

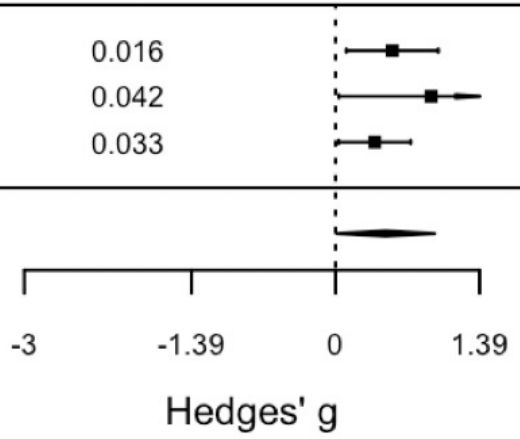


Response Time

Hedges' g = -0.01, p = 0.90

Results

Author(s) and Year	Picture Type	Sample Size	Z-val	P-val	Weight, Hedges' g [95% CI]
Garcia-retamero & Hoffrage, 2013b	Organizational	80	2.417	0.016	34.73% 0.55 [0.10, 0.99]
Dewolf, Van Dooren, Hermens, & Verschaffel, 2015	Representational	20	2.033	0.042	8.64% 0.92 [0.03, 1.81]
Lindner, Eitel, Barenthien, & Köller, 2018a	Representational	129	2.133	0.033	56.63% 0.38 [0.03, 0.72]
RE Model for All Studies (Q = 1.37, df = 2, p = 0.50; I^2 = 0.0%)					100.00% 0.48 [0.01, 0.96]



Response Certainty

Hedges' g = 0.48, p = 0.05

Discussion

H1 Multimedia Effect on Response Accuracy ✓

H4 Moderators: Picture function+Problem difficulty ✓

- Function type of pictures
  Only Representational and Organisational pictures
- Problem difficulty
  Only for Difficult Problems

Discussion

Response Accuracy

Moderating effect of problem difficulty conforms to the element interactivity effect

- Interactivity effect occurs when multimedia effects present in high intrinsic cognitive load conditions disappear or even reverse in low intrinsic cognitive load conditions (Chen et al., 2015; Chen, Kalyuga, & Sweller, 2016).

Discussion

Response Accuracy

Moderating effect of picture function challenges *Less is more* in classic multimedia learning theories.

- Informational pictures have little impact.
- Representational, organisational and decorative pictures are not harmful.

Discussion

Response Time

2

Multimedia Effect on Response Time

A single response time may be inadequate to measure the multimedia problem-solving performance

Discussion

Response Certainty

3

Multimedia Effect on Response Certainty

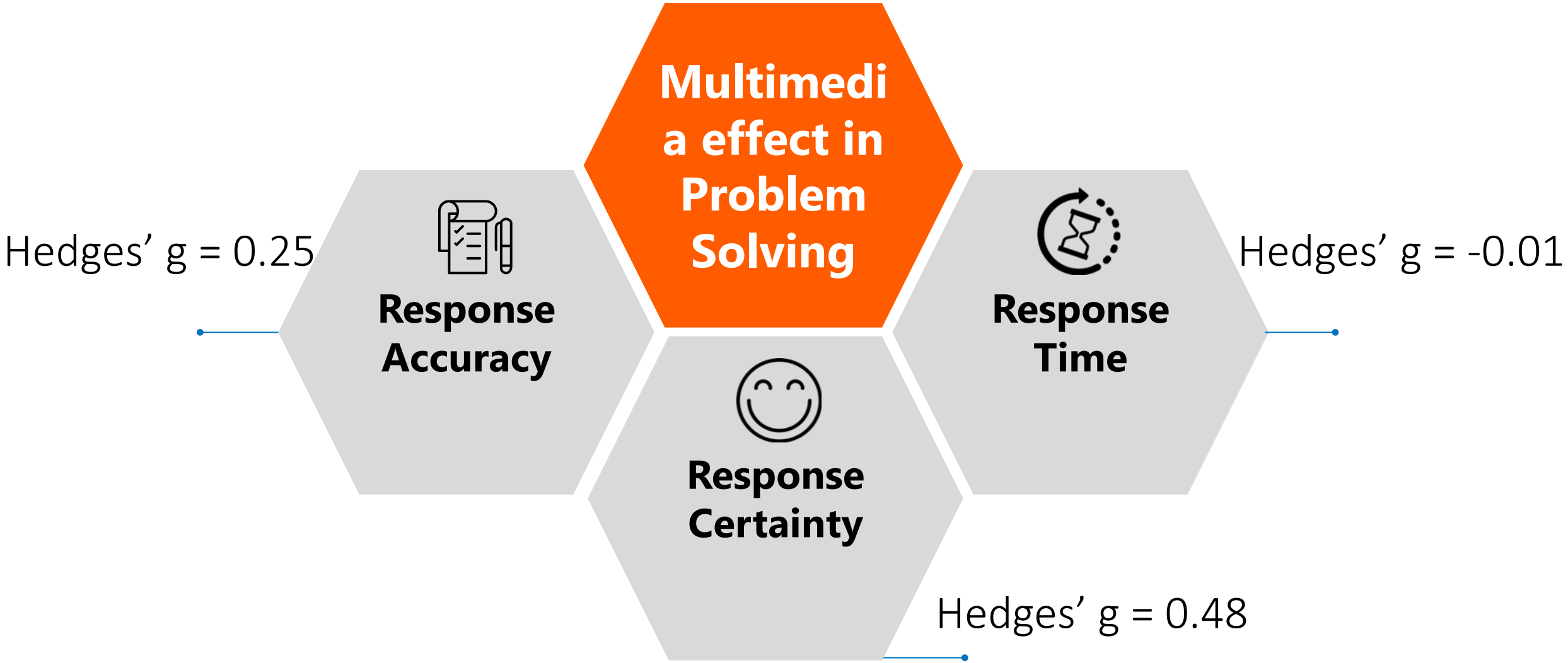
Motivation, Engagement, Pleasure, Self-efficacy

Less critical with text
Decreased time spent processing text
Suboptimal restudy behavior etc.

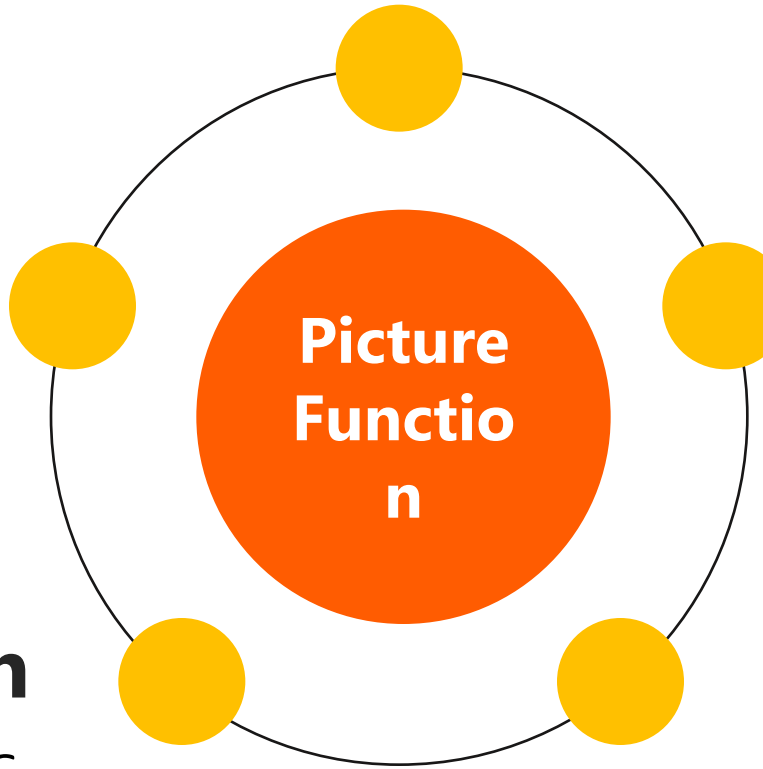
Limitation

- Quality of studies is not strictly evaluated
- More moderators need to be identified and analysed

Conclusion


Multimedia effect in Problem Solving
Response Accuracy
Hedges' g = 0.25
Response Time
Hedges' g = -0.01
Response Certainty
Hedges' g = 0.48

Conclusion



Information
Hedges' *g* = 0.08

Representational
Hedges' g = 0.18

Decorative
Hedges' *g* = 0.00

Organizational
Hedges' g = 0.46

Multiple
Hedges' *g* = 0.48

Which one is better?

A full water tank on a water dispenser contains 20 liter.
Students from the dispenser fill their 25 cl water bottles.

How many water bottles can be filled from a full water tank?

☐ **bottles**

How many water bottles can be filled from a full water tank?

☐ **bottles**

Implication

- There are still very few design principles guiding multimedia item designs.

- Existing multimedia learning principles are not enough to guide multimedia item design.

- Embedding multimedia can facilitate item access and accommodation, it may also lots of issues that have yet to be fully explored. Further prospective studies are in urgent need.

References

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293-332.

Chen, O., Kalyuga, S., & Sweller, J. (2015). The worked example effect, the generation effect, and element interactivity. *Journal of Educational Psychology*, *107*(3), 689-704. http://doi.org/10.1037/edu0000018

Elia, I., & Philippou, G. (2004). The functions of pictures in problem solving. In M. Johnsen Hoines, & A. Berit Fuglestad (Eds.), *Proceedings of the 28th Conference of the International Group for the Psychology of Mathematics Education*: *Vol. 2* (pp. 327-334). Bergen: PME.

Fuchs, L. S., Fuchs, D., Compton, D. L., Hamlett, C. L., & Wang, A. Y. (2015). Is word-problem solving a form of text comprehension? *Scientific Studies of Reading*, *19*(3), 204-223. http://doi.org/10.1080/10888438.2015.1005745

Hoogland, K., de Koning, J., Bakker, A., Pepin, B. E. U., & Gravemeijer, K. (2018). Changing representation in contextual mathematical problems from descriptive to depictive: The effect on students' performance. *Studies in Educational Evaluation*, *58*(June), 122-131. http://doi.org/10.1016/j.stueduc.2018.06.004

Hoogland, K., Pepin, B., de Koning, J., Bakker, A., & Gravemeijer, K. (2018). Word problems versus image-rich problems: An analysis of effects of task characteristics on students' performance on contextual mathematics problems. *Research in Mathematics Education*, *20*(1), 37-52. http://doi.org/10.1080/14794802.2017.1413414

Lindner, M. A., Lüdtke, O., Grund, S., & Köller, O. (2017). The merits of representational pictures in educational assessment: Evidence for cognitive and motivational effects in a time-on-task analysis. *Contemporary Educational Psychology*, *51*(September), 482-492. http://doi.org/10.1016/j.cedpsych.2017.09.009

References

Mayer, R. E., & Fiorella, L. (2014). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. In R. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning, Second Edition* (pp. 279-315). Cambridge: Cambridge University Press. http://doi.org/10.1017/CBO9781139547369.015

McCabe, D. P., & Castel, A. D. (2008). Seeing is believing: The effect of brain images on judgments of scientific reasoning. *Cognition*, *107*(1), 343-352. http://doi.org/10.1016/j.cognition.2007.07.017

Ögren, M., Nyström, M., & Jarodzka, H. (2017). There's more to the multimedia effect than meets the eye: Is seeing pictures believing? *Instructional Science*, *45*(2), 263-287. http://doi.org/10.1007/s11251-016-9397-6

Saß, S., & Schütte, K. (2016). Helping poor readers demonstrate their science competence: Item characteristics supporting text-picture integration. *Journal of Psychoeducational Assessment*, *34*(1), 91-96. http://doi.org/10.1177/0734282915588389

Saß, S., Schütte, K., & Lindner, M. A. (2017). Test-takers' eye movements: Effects of integration aids and types of graphical representations. *Computers and Education*, *109*, 85-97. http://doi.org/10.1016/j.compedu.2017.02.007

Saß, S., Wittwer, J., Senkbeil, M., & Köller, O. (2012). Pictures in test items: Effects on response time and response correctness. *Applied Cognitive Psychology*, *26*(1), 70-81.

Schneider, S., Nebel, S., & Rey, G. D. (2016). Decorative pictures and emotional design in multimedia learning. *Learning and Instruction*, *44*(March), 65-73. http://doi.org/10.1016/j.learninstruc.2016.03.002


Thank You

Main Code	Category
Outcome	*Response accuracy/response time/response certainty.*
Function type	*Decorative/representational/organisational/informational/ multiple.*
Experimental design	*between group design/within group design, and other.*
Control condition	*Yes/No*
Domain	*Mathematics/Science/Language/Medicine.*
Educational stage	*Primary/university/other.*
Problem size	The number of problems in one group.
Answer format	*Multiple-choice/structured open response*
Problem difficulty	*Easy/difficult*
Testing environment	*Paper and pencil/computer-based*

Possible Moderators	Q	I^2	p-value	k	Effect size (Hedges' g)	95% CI for Hedges' g
Problem size	—	—	0.502	28	0.00	[-0.008, 0.02]
Problem difficulty**	248.93	96.24 %	0.124	14	0.27	[-0.09, 0.63]
(2) Difficult	34.05	79.91 %	0.005**	14	0.17	[0.06, 0.27]
Domain*						
(1) Science	107.81	95.67 %	0.300	14	0.16	[-0.15, 0.46]
(2) Math	327.42	97.65 %	0.030*	9	0.32	[0.04, 0.60]
(3) Medicine	17.38	85.71 %	0.160	3	0.56	[-0.54, 1.65]
(4) Language	0.00	0.00 %	0.020*	2	0.07	[0.03, 0.10]
Answer format**						
(1) Multiple-choice	66.62	83.86 %	0.000**	13	0.31	[0.17, 0.44]
(2) Structured open response	380.71	97.96 %	0.250	15	0.18	[-0.15, 0.51]
Testing environment***						
(1) Computer based	52.22	90.74 %	0.003**	12	0.36	[0.15, 0.56]
(2) Paper and pencil	338.00	96.99 %	0.269	16	0.15	[-0.12, 0.42]
Educational stage						
(1) Primary	46.25	78.72 %	0.005**	11	0.21	[0.08, 0.35]
(2) University	192.57	95.36 %	0.280	11	0.24	[-0.23, 0.70]
(3) Other	26.13	97.55 %	0.107	6	0.29	[-0.09,0.67]
Sample size	—	—	0.696	28	0.00	[-0.00, 0.00]
Control condition**						
(1) Without control variables	258.68	96.82 %	0.032*	9	0.32	[0.03, 0.60]
(2) With single or multiple control variables	152.43	95.31 %	0.079	19	0.21	[-0.03, 0.45]
Institution location**						
(1) Europe	90.78	86.41 %	0.000**	15	0.28	[0.15, 0.41]
(2) United States	80.74	96.78 %	0.630	10	0.11	[-0.38, 0.60]
(3) Other	174.76	98.68 %	0.290	3	0.41	[-0.82, 1.65]
Experimental design**						
(1) Within group design	363.56	98.40 %	0.016*	10	0.31	[0.07, 0.55]
(2) Between group design	98.70	89.07 %	0.113	18	0.11	[-0.05, 0.46]

Some other moderators on response accuracy