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Computer programming skills: A cognitive perspective

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DOI:

[10.33612/diss.168003240](https://doi.org/10.33612/diss.168003240)

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Document Version

Publisher's PDF, also known as Version of record

Publication date:
2021

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Graafsma, I. (2021). *Computer programming skills: A cognitive perspective*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen. <https://doi.org/10.33612/diss.168003240>

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References

References

- Aho, A. V., Lam, M. S., Sethi, R., & Ullman, J. D. (2007). *Compilers: Principles, techniques, and tools. Second edition*. New York: Pearson Education Addison Wesley.
- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: Author.
- Armoni, M. (2013). On teaching abstraction in CS to novices. *Journal of Computers in Mathematics and Science Teaching*, 32(3), 265-284.
- Austin, E. J. (2005). Personality correlates of the broader autism phenotype as assessed by the Autism Spectrum Quotient (AQ). *Personality and Individual Differences*, 38(2), 451–460. <https://doi.org/10.1016/j.paid.2004.04.022>
- Bailey, J., & Mitchell, R. B. (2006). Industry perceptions of the competencies needed by computer programmers: technical, business, and soft skills. *Journal of Computer Information Systems*, 47(2), 28-33. <https://doi.org/10.1080/08874417.2007.-11645951>
- Balanskat, A., & Engelhardt, K. (2015). *Computing our future: Computer programming and coding - Priorities, school curricula and initiatives across Europe*. European Schoolnet. http://www.eun.org/c/document_library/get_file?uuid=3596b121-941c-4296-a760-0f4e4795d6fa&groupId=43887.
- Baron-Cohen, S. (2006). The hyper-systemizing, assortative mating theory of autism. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 30(5), 865–872. <https://doi.org/10.1016/j.pnpbp.2006.01.010>
- Baron-Cohen, S. (2008). *Autism and Asperger syndrome*. Oxford, UK: Oxford University Press.
- Baron-Cohen, S. (2012). Autism and the technical mind. *Scientific American*, 307(5), 72–75.
- Baron-Cohen, S., Wheelwright, S., Burtenshaw, A., & Hobson, E. (2007). Mathematical Talent is Linked to Autism. *Human Nature*, 18(2), 125–131. <https://doi.org/10.1007/s12110-007-9014-0>
- Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, 31(1), 5–17. <https://doi.org/10.1023/A:1005653411471>
- Barrick, M. R., Mount, M. K., & Judge, T. A. (2001). Personality and performance at the beginning of the new millennium: What do we know and where do we go next? *International Journal of Selection and Assessment*, 9(1 & 2), 9–30. <https://doi.org/10.1111/1468-2389.00160>
- Bednarik, R., & Tukiainen, M. (2006). An eye-tracking methodology for characterizing program comprehension processes. *Proceedings of the 2006 symposium on eye tracking research & applications*, 125-132. <https://doi.org/10.1145/1117309.1117356>

- Bergin Jr, T. J., & Gibson Jr, R. G. (1996). *History of programming languages---II*. New York, NY: ACM Press and Addison-Wesley. <https://doi.org/10.1145/234286>
- Borzovs, J., Kozmina, N., Niedrite, L., Solodovnikova, D., Straujums, U., Zuters, J., & Klavins, A. (2017). Can SQ and EQ Values and Their Difference Indicate Programming Aptitude to Reduce Dropout Rate? In M. Kirikova, K. Nørvåg, G. A. Papadopoulos, J. Gamper, R. Wrembel, J. Darmont, & S. Rizzi (Eds.), *New Trends in Databases and Information Systems 767*, 285–293. Cham, CH: Springer International Publishing. https://doi.org/10.1007/978-3-319-67162-8_28
- Brooks, R. (1977). Towards a theory of the cognitive processes in computer programming. *International Journal of Man-Machine Studies*, 9(6), 737-751. doi:[https://doi.org/10.1016/S0020-7373\(77\)80039-4](https://doi.org/10.1016/S0020-7373(77)80039-4)
- Brooks, R. (1978). Using a behavioral theory of program comprehension in software engineering. *Proceedings of the 3rd International Conference on Software Engineering*, 196-201.
- Brooks, R. (1983). Towards a theory of the comprehension of computer programs. *International Journal Man-Machine Studies*, 18(6), 543-554. doi:[https://doi.org/10.1016/S0020-7373\(83\)80031-5](https://doi.org/10.1016/S0020-7373(83)80031-5)
- Brusilovsky, P., Calabrese, E., Hvorecky, J., Kouchnirenko, A., & Miller, P. (1997). Mini-languages: a way to learn programming principles. *Education and Information Technologies*, 2(1), 65-83. <https://doi.org/10.1023/A:1018636507883>
- Carreiras, M., & Clifton Jr, C. (2004). *The on-line study of sentence comprehension: Eyetracking, ERPs and beyond*. New York, NY: Psychology Press.
- Catherine, B.-C., & Wheeler, D. D. (1994). The Myers-Briggs Personality Type and Its Relationship to Computer Programming. *Journal of Research on Computing in Education*, 26(3), 358–370. <https://doi.org/10.1080/08886504.1994.10782096>
- Chen, L., Shu, H. U. A., Liu, Y., Zhao, J., & Li, P. (2007). ERP signatures of subject–verb agreement in L2 learning. *Bilingualism: Language and Cognition*, 10(2), 161-174. <https://doi.org/10.1017/S136672890700291X>
- Coles, M., & Phalp, K. T. (2016). *Brain type as a programming aptitude predictor*. PPIG 2016 – 27th Annual Workshop.
- Coulson, S., King, J. W., & Kutas, M. (1998). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and Cognitive Processes*, 13(1), 21-58. <https://doi.org/10.1080/016909698386582>
- Dasgupta, S. (2014). *It began with Babbage: The genesis of computer science*. Oxford, UK: Oxford University Press.

References

- den Houting, J. (2019). Neurodiversity: An insider's perspective. *Autism*, 23(2), 271–273. <https://doi.org/10.1177/1362361318820762>
- Donchin, E. (1981). Surprise! . . . Surprise? *Psychophysiology*, 18, 493–513. <https://doi.org/10.1111/j.1469-8986.1981.tb01815.x>
- European commission (2018). *Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions on the Digital Education Action Plan*. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A22%3AFIN>
- Europees Referentiekader Talen. (n.d.). Niveaus havo/vwo. <https://erk.nl/docent/streefniveaus/havo/>
- European Schoolnet. (2015, November 30). Computing our future. Computer programming and coding. Priorities, school curricula and initiatives across Europe. Retrieved from http://www.eun.org/c/document_library/get_file?uuid=3596b121-941c-4296-a760-0f4e4795d6fa&groupId=43887.
- Essinger, J. (2004). *Jacquard's web: How a hand-loom led to the birth of the information age*. Oxford, UK: OUP Oxford.
- Fedorenko, E., Ivanova, A., Dhamala, R., & Bers, M. U. (2019). The language of programming: A cognitive perspective. *Trends in Cognitive Sciences*, 23(7), 525–528. <https://doi.org/10.1016/j.tics.2019.04.010>
- Floyd, B., Santander, T., & Weimer, W. (2017). Decoding the representation of code in the brain: An fMRI study of code review and expertise. *2017 IEEE/ACM 39th International Conference on Software Engineering (ICSE)*, 175–186. IEEE. <https://doi.org/10.1109/ICSE.2017.24>
- Focquaert, F., Steven, M. S., Wolford, G. L., Colden, A., & Gazzaniga, M. S. (2007). Empathizing and systemizing cognitive traits in the sciences and humanities. *Personality and Individual Differences*, 43(3), 619–625. <https://doi.org/10.1016/j.paid.2007.01.004>
- Friederici, A. D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language*, 50(3), 259–281. <https://doi.org/10.1006/brln.1995.1048>
- Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences*, 6(2), 78–84. [https://doi.org/10.1016/S1364-6613\(00\)01839-8](https://doi.org/10.1016/S1364-6613(00)01839-8)
- Friederici, A. D., Hahne, A., & Saddy, D. (2002). Distinct neurophysiological patterns reflecting aspects of syntactic complexity and syntactic repair. *Journal of Psycholinguistic Research*, 31(1), 45–63. <https://doi.org/10.1023/A:1014376204525>

- Fuegi, J., & Francis, J. (2003). Lovelace & Babbage and the creation of the 1843 'notes'. *IEEE Annals of the History of Computing*, 25(4), 16-26.
<https://doi.org/10.1109/MAHC.2003.1253887>
- Gazzaniga, M.S., Ivry, R.B., & Mangin, G.R. (2009). *Cognitive neuroscience: The biology of the mind* (3rd ed.). New York, NY: W.W. Norton & Company.
- Golding, P., Facey-Shaw, L., & Tennant, V. (2006). Effects of peer tutoring, attitude and personality on academic performance of first year introductory programming students. *Proceedings. Frontiers in Education. 36th Annual Conference*, 7–12.
<https://doi.org/10.1109/FIE.2006.322662>
- Gosling, J., Joy, B., Steele, G., & Bracha, G. (2000). *The Java language specification*. Boston, MA: Addison-Wesley Professional.
- Gouvea, A. C., Phillips, C., Kazanina, N., & Poeppel, D. (2010). The linguistic processes underlying the P600. *Language and Cognitive Processes*, 25(2), 149-188.
<https://doi.org/10.1080/01690960902965951>
- Gray, K. E., & Flatt, M. (2003). ProfessorJ: A gradual introduction to Java through language levels. *Companion of the 18th annual ACM SIGPLAN conference on Object-oriented programming, systems, languages, and applications*, 170-177.
<https://doi.org/10.1145/949344.949394>
- Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika*, 24(2), <https://doi.org/95-112.10.1007/BF02289823>
- Grover, S., Jackiw, N., & Lundh, P. (2019). Concepts before coding: non-programming interactives to advance learning of introductory programming concepts in middle school. *Computer Science Education*, 29(2-3), 106-135.
<https://doi.org/10.1080/08993408.2019.1568955>
- Guzdial, M. (2003). A media computation course for non-majors. *Proceedings of the 8th Annual Conference on Innovation and Technology in Computer Science Education*, 104–108.
<https://doi.org/10.1145/961511.961542>
- Guzdial, M. (2015). Learner-centered design of computing education: Research on computing for everyone. *Synthesis Lectures on Human-Centered Informatics*, 8(6), 1-165.
<https://doi.org/10.2200/S00684ED1V01Y201511HCI033>
- Guzdial, M. (2019, August 26). Holding ourselves to a higher standard: “Language-independent” just doesn’t cut it. *Computing Education Research Blog*.
<https://computinged.wordpress.com/2019/08/26/the-temptation-in-computing-education-research-to-claim-language-independence/>

References

- Guzdial, M., & du Boulay, B. (2019). The history of computing education research. *The Cambridge handbook of computing education research* (pp. 11–39). Cambridge, UK: Cambridge University Press.
- Hackerrank (2018, January 23). *Developer skills report*. Retrieved from <http://research.hackerrank.com/developer-skills/2018/>.
- Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech compared to reading: the P600/SPS to syntactic violations in spoken sentences and rapid serial visual presentation. *Neuropsychologia*, 38(11), 1531-1549. [https://doi.org/10.1016/S0028-3932\(00\)00053-1](https://doi.org/10.1016/S0028-3932(00)00053-1)
- Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes*, 8(4), 439-483. <https://doi.org/10.1080/01690969308407585>
- Handley, S. J., Capon, A., Copp, C., & Harper, C. (2002). Conditional reasoning and the Tower of Hanoi: The role of spatial and verbal working memory. *British Journal of Psychology*, 93(4), 501–518. <https://doi.org/10.1348/000712602761381376>
- Hermans, F. (2020). Hedy: A Gradual Language for Programming Education. *Proceedings of the 2020 ACM Conference on International Computing Education Research*, 259-270. <https://doi.org/10.1145/3372782.3406262>
- Hermans, F., & Aldewereld, M. (2017). Programming is writing is programming. *Companion to the First International Conference on the Art, Science and Engineering of Programming*, 1–8. <https://doi.org/10.1145/3079368.3079413>
- Hoekstra, R. A., Bartels, M., Cath, D. C., & Boomsma, D. I. (2008). Factor Structure, Reliability and Criterion Validity of the Autism-Spectrum Quotient (AQ): A Study in Dutch Population and Patient Groups. *Journal of Autism and Developmental Disorders*, 38(8), 1555–1566. <https://doi.org/10.1007/s10803-008-0538-x>
- Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology*, 30(1), 47-61. <https://doi.org/10.1111/j.1469-8986.1993.tb03204.x>
- Hurst, R. M., Mitchell, J. T., Kimbrel, N. A., Kwapiel, T. K., & Nelson-Gray, R. O. (2007). Examination of the reliability and factor structure of the Autism Spectrum Quotient (AQ) in a non-clinical sample. *Personality and Individual Differences*, 43(7), 1938–1949. <https://doi.org/10.1016/j.paid.2007.06.012>
- IBM (Ed.) 1968 *Aptitude test for programmer personnel*. New York: International Business Machines Corporation.

- Ivanova, A. A., Srikant, S., Sueoka, Y., Kean, H. H., Dhamala, R., O'reilly, U. M., ... & Fedorenko, E. (2020). Comprehension of computer code relies primarily on domain-general executive resources. *BioRxiv*. <https://doi.org/10.1101/2020.04.16.045732>
- Jost, K., Henninghausen, E., & Rosler, F. (2004). Comparing arithmetic and semantic fact retrieval: Effects of problem size and sentence constraint on event-related brain potentials. *Psychophysiology*, 41, 46–59. <https://doi.org/10.1111/1469-8986.00119>
- Kaan, E. (2002). Investigating the effects of distance and number interference in processing subject-verb dependencies: An ERP study. *Journal of Psycholinguistic Research*, 31(2), 165-193. <https://doi.org/10.1023/A:1014978917769>
- Kanne, S. M., Wang, J., & Christ, S. E. (2011). The Subthreshold Autism Trait Questionnaire (SATQ): Development of a brief self-report measure of subthreshold autism traits. *Journal of Autism and Developmental Disorders*, 42(5), 769–780. <https://doi.org/10.1007/s10803-011-1308-8>
- Kelleher, C., & Pausch, R. (2003). Lowering the barriers to programming. *ACM Computing*.
- Kline, R. (2005). *Principles and practices of structural equation modeling* (2n ed.). New York: Guilford Press.
- Kotz, S. A. (2009). A critical review of ERP and fMRI evidence on L2 syntactic processing. *Brain and Language*, 109(2-3), 68-74. <https://doi.org/10.1016/j.bandl.2008.06.002>
- Knuth, D. E., & Pardo, L. T. (1980). The early development of programming languages. In *A history of computing in the twentieth century* (pp. 197-273). New York, NY: Marcel Dekker. <https://doi.org/10.1016/B978-0-12-491650-0.50019-8>
- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic anomaly. *Science*, 207, 203-205. <https://doi.org/10.1126/science.7350657>
- Lance, C. E., Butts, M. M., & Michels, L. C. (2006). The sources of four commonly reported cutoff criteria: What did they really say? *Organizational Research Methods*, 9(2), 202-220. <https://doi.org/10.1177/1094428105284919>
- Landry, O., & Chouinard, P. A. (2016). Why we should study the broader autism phenotype in typically developing populations. *Journal of Cognition and Development*, 17(4), 584–595. <https://doi.org/10.1080/15248372.2016.1200046>
- Lenroot, R. K., & Yeung, P. K. (2013). Heterogeneity within autism spectrum disorders: What have we learned from neuroimaging studies? *Frontiers in Human Neuroscience*, 7. <https://doi.org/10.3389/fnhum.2013.00733>
- Lord, C., Cook, E. H., Leventhal, B. L., & Amaral, D. G. (2000). Autism spectrum disorders. *Neuron*, 28(2), 355–363.

References

- Lu, J. J., & Fletcher, G. H. (2009). Thinking about computational thinking. *Proceedings of the 40th ACM technical symposium on computer science education*, 260-264. <https://doi.org/10.1145/1508865.1508959>
- Lukey, F. J. (1980). Understanding and debugging programs. *International Journal of Man-Machine Studies*, 12(2), 189-202. [https://doi.org/10.1016/S0020-7373\(80\)80017-4](https://doi.org/10.1016/S0020-7373(80)80017-4)
- Marasco, E. A., Moshirpour, M., & Moussavi, M. (2017). Flipping the foundation: A multi-year flipped classroom study for a large-scale introductory programming course. [Paper presentation]. *ASEE Annual Conference & Exposition, Columbus, Ohio, USA*. <https://peer.asee.org/28372>
- Marston, D., Fuchs, L. S., & Deno, S. L. (1986). Measuring pupil progress: A comparison of standardized achievement tests and curriculum-related measures. *Diagnostique*, 11(2), 77-90. <https://doi.org/10.1177/073724778601100203>
- McCracken, M., Almstrum, V., Diaz, D., Guzdial, M., Hagan, D., Kolikant, Y. B. D., ... & Wilusz, T. (2001). A multi-national, multi-institutional study of assessment of programming skills of first-year CS students. *ACM SIGCSE Bulletin* 33(4), 125-180. <https://doi.org/10.1145/572133.572137>
- Milton, D. E. M. (2012). On the ontological status of autism: The 'double empathy problem.' *Disability & Society*, 27(6), 883-887. <https://doi.org/10.1080/09687599.2012.710008>
- Mitchell, P., Cassidy, S., & Sheppard, E. (2019). The double empathy problem, camouflage, and the value of expertise from experience. *Behavioral and Brain Sciences*, 42, e100. <https://doi.org/10.1017/S0140525X18002212>
- Molinaro, N., Vespiagnani, F., & Job, R. (2008). A deeper reanalysis of a superficial feature: An ERP study on agreement violations. *Brain Research*, 1228, 161-176. <https://doi.org/10.1016/j.brainres.2008.06.064>
- Morgan-Short, K., Steinhauer, K., Sanz, C., & Ullman, M. T. (2012). Explicit and implicit second language training differentially affect the achievement of native-like brain activation patterns. *Journal of Cognitive Neuroscience*, 24(4), 933-947. https://doi.org/10.1162/jocn_a_00119
- Mulyanto, H., Gunarhadi, G., & Indriayu, M. (2018). The effect of problem based learning model on student mathematics learning outcomes viewed from critical thinking skills. *International Journal of Educational Research Review*, 3(2), 37-45. <https://doi.org/10.24331/ijere.408454>

- Murray, A. L., McKenzie, K., Kuenssberg, R., & Booth, T. (2017). Do the Autism Spectrum Quotient (AQ) and Autism Spectrum Quotient Short Form (AQ-S) primarily reflect general ASD traits or specific ASD traits? A bi-factor analysis. *Assessment*.
<https://doi.org/10.1177/1073191115611230>
- Nelson, G. L., Xie, B., & Ko, A. J. (2017). Comprehension first: Evaluating a novel pedagogy and tutoring system for program tracing in CS1. *Proceedings of the 2017 ACM Conference on International Computing Education Research*, 2-11.
<https://doi.org/10.1145/3105726.3106178>
- Nevins, A., Dillon, B., Malhotra, S., & Phillips, C. (2007). The role of feature-number and feature-type in processing Hindi verb agreement violations. *Brain Research*, 1164, 81-94.
<https://doi.org/10.1016/j.brainres.2007.05.058>
- Nishiyama, T., Suzuki, M., Adachi, K., Sumi, S., Okada, K., Kishino, H., ... & Kanne, S. M. (2014). Comprehensive comparison of self-administered questionnaires for measuring quantitative autistic traits in adults. *Journal of Autism and Developmental Disorders*, 44(5), 993-1007.
<https://doi.org/10.1007/s10803-013-2020-7>
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), 97-113.
[https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)
- O'Regan, G. (2012). History of programming languages. In *A Brief History of Computing* (pp. 121–144). London, UK: Springer. https://doi.org/10.1007/978-1-4471-2359-0_9
- Osterhout, L. (1999). A superficial resemblance does not necessarily mean you are part of the family: Counterarguments to Coulson, King and Kutas (1998) in the P600/SPS-P300 debate. *Language and Cognitive Processes*, 14(1), 1-14.
<https://doi.org/10.1080/016909699386356>
- Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language*, 31(6), 785-806.
[https://doi.org/10.1016/0749-596X\(92\)90039-Z](https://doi.org/10.1016/0749-596X(92)90039-Z)
- Osterhout, L., & Holcomb, P. J. (1995). *Event related potentials and language comprehension*. In M. D. Rugg & M. G. H. Coles (Eds.), *Oxford psychology series, No. 25. Electrophysiology of mind: Event-related brain potentials and cognition* (p. 171–215). Oxford, UK: Oxford University Press.
- Osterhout, L., McKinnon, R., Bersick, M., & Corey, V. (1996). On the language specificity of the brain response to syntactic anomalies: Is the syntactic positive shift a member of the P300 family?. *Journal of Cognitive Neuroscience*, 8(6), 507-526.

References

- <https://doi.org/10.1162/jocn.1996.8.6.507>
- Pandža, N. B. (2016). Computer Programming as a Second Language. In *Advances in human factors in cybersecurity* (pp. 439–445). Cham, CH: Springer.
https://doi.org/10.1007/978-3-319-41932-9_36
- Parker, M. C., Guzdial, M., & Engleman, S. (2016). Replication, validation, and use of a language independent CS1 knowledge assessment. *Proceedings of the 2016 ACM Conference on International Computing Education Research*, 93-101.
<https://doi.org/10.1145/2960310.2960316>
- Parker, M. C., Solomon, A., Pritchett, B., Illingworth, D. A., Marguilieux, L. E., & Guzdial, M. (2018). Socioeconomic status and computer science achievement: Spatial ability as a mediating variable in a novel model of understanding. *Proceedings of the 2018 ACM Conference on International Computing Education Research*, 97-105.
<https://doi.org/10.1145/3230977.3230987>
- Paulson, L. D. (2007). Developers shift to dynamic programming languages. *Computer*, 40(2), 12–15. <https://doi.org/10.1109/MC.2007.53>
- Pea, R. D., & Kurland, D. M. (1984). On the cognitive effects of learning computer programming. *New Ideas in Psychology*, 2(2), 137–168. [https://doi.org/10.1016/0732-118X\(84\)90018-7](https://doi.org/10.1016/0732-118X(84)90018-7)
- Pena, C. M., & Tirre, W. C. (1992). Cognitive factors involved in the first stage of programming skill acquisition. *Learning and Individual Differences*, 4(4), 311–334.
[https://doi.org/10.1016/1041-6080\(92\)90017-9](https://doi.org/10.1016/1041-6080(92)90017-9)
- Perrenet, J., Groote, J. F., & Kaasenbrood, E. (2005). Exploring students' understanding of the concept of algorithm: Levels of abstraction. *ACM SIGCSE Bulletin*, 37(3), 64-68.
<https://doi.org/10.1145/1151954.1067467>
- Pimsleur, P., Reed, D. J., & Stansfield, C. W. (2004). *Pimsleur language aptitude battery: Manual 2004 edition*. Bethesda, MD: Second Language Testing.
- Polito, V., Barnier, A. J., & Woody, E. Z. (2013). Developing the Sense of Agency Rating Scale (SOARS): An empirical measure of agency disruption in hypnosis. *Consciousness and Cognition*, 22(3), 684-696. <https://doi.org/10.1016/j.concog.2013.04.003>
- Portnoff, S. R. (2018). The introductory computer programming course is first and foremost a language course. *ACM Inroads*, 9(2), 34-52. <https://doi.org/10.1145/3152433>
- Potts, G. F. (2004). An ERP index of task relevance evaluation of visual stimuli. *Brain and Cognition*, 56(1), 5-13. <https://doi.org/10.1016/j.bandc.2004.03.006>

- Prat, C. S., Madhyastha, T. M., Mottarella, M. J., & Kuo, C. H. (2020). Relating natural language aptitude to individual differences in learning programming languages. *Scientific Reports*, 10(1), 1-10. <https://doi.org/10.1038/s41598-020-60661-8>
- Qualtrics (Version 2019). (2005). [Survey software]. Qualtrics. <https://www.qualtrics.com>.
- Rayner, K. (2009). Eye movements in reading: Models and data. *Journal of Eye Movement Research*, 2(5), 1-10.
- Robins, A., Margulieux, L. E., & Morrison, B. B. (2019). Cognitive sciences for computing education. In S. Fincher & A. Robins (Eds.), *Handbook of computing education research* (pp. 231--275). Cambridge, UK: Cambridge University Press.
- Rogers, V., Meara, P., Barnett-Legh, T., Curry, C., & Davie, E. (2017). Examining the LLAMA aptitude tests. *Journal of the European Second Language Association*, 1(1). <http://doi.org/10.22599/jesla.24>
- Romanova, A. (2015). *Word class effects on representation and processing in non-brain damaged speakers and people with aphasia*. [Doctoral dissertation, Macquarie University]. Macquarie University Library. <https://www.researchonline.mq.edu.au/vital/access/services/Download/mq:44500/SOURCE1?view=true>
- Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian t tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review*, 16(2), 225-237. <https://doi.org/10.3758/PBR.16.2.225>
- Rushkoff (2012). Code literacy: A 21st-century requirement. *Edutopia*. Available at: <https://www.edutopia.org/blog/code-literacy-21st-century-requirement-douglas-rushkoff>
- Rossi, S., Gugler, M. F., Friederici, A. D., & Hahne, A. (2006). The impact of proficiency on syntactic second-language processing of German and Italian: Evidence from event-related potentials. *Journal of Cognitive Neuroscience*, 18(12), 2030-2048. <https://doi.org/10.1162/jocn.2006.18.12.2030>
- Ruzich, E., Allison, C., Smith, P., Watson, P., Auyeung, B., Ring, H., & Baron-Cohen, S. (2015). Measuring autistic traits in the general population: A systematic review of the Autism-Spectrum Quotient (AQ) in a nonclinical population sample of 6,900 typical adult males and females. *Molecular Autism*, 6(1), 2. <https://doi.org/10.1186/2040-2392-6-2>
- Sassenhagen, J., & Fiebach, C. J. (2019). Finding the P3 in the P600: Decoding shared neural mechanisms of responses to syntactic violations and oddball targets. *NeuroImage*, 200, 425-436. <https://doi.org/10.1016/j.neuroimage.2019.06.048>

References

- Sassenhagen, J., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2014). The P600-as-P3 hypothesis revisited: Single-trial analyses reveal that the late EEG positivity following linguistically deviant material is reaction time aligned. *Brain and Language*, 137, 29-39. <https://doi.org/10.1016/j.bandl.2014.07.010>
- Seegerer, S., Michaeli, T., & Romeike, R. (2019). Informatik für alle-Eine Analyse von Argumenten und Argumentationsschemata für das Schulfach Informatik [Computer science for everyone - an analysis of arguments and argumentation schemes for the school subject computer science.]. *INFORMATIK 2019: 50 Jahre Gesellschaft für Informatik-Informatik für Gesellschaft*. https://doi.org/10.18420/inf2019_77
- Shute, V. J. (1991). Who is likely to acquire programming skills? *Journal of Educational Computing Research*, 7(1), 1–24. <https://doi.org/10.2190/VQJD-T1YD-5WVB-RYPJ>
- Siegmund, J., Kästner, C., Apel, S., Parnin, C., Bethmann, A., Leich, T., ... & Brechmann, A. (2014). Understanding source code with functional magnetic resonance imaging. *Proceedings of the 36th International Conference on Software Engineering*, 378-389. ACM. <https://doi.org/10.1145/2568225.2568252>
- Skehan, P. (1991). Individual differences in second language learning. *Studies in Second Language Acquisition*, 13(2), 275–298. <https://doi.org/10.1017/S0272263100009979>
- Stevenson, J. L., & Hart, K. R. (2017). Psychometric properties of the Autism-Spectrum Quotient for assessing low and high levels of autistic traits in college students. *Journal of Autism and Developmental Disorders*, 47(6), 1838–1853. <https://doi.org/10.1007/s10803-017-3109-1>
- Suárez-Pellicioni, M., Núñez-Peña, M. I., & Colomé, A. (2013). Mathematical anxiety effects on simple arithmetic processing efficiency: An event-related potential study. *Biological Psychology*, 94(3), 517-526. <https://doi.org/10.1016/j.biopsych.2013.09.012>
- Szucs, D., & Csépe, V. (2004). Access to numerical information is dependent on the modality of stimulus presentation in mental addition: A combined ERP and behavioral study. *Cognitive Brain Research*, 19, 10–27. <https://doi.org/10.1016/j.cogbrainres.2003.11.002>
- Tew, A.E. 2010. *Assessing fundamental introductory computing concept knowledge in a language independent manner*. [Doctoral dissertation, Georgia Institute of Technology]. Georgia Tech Library. <https://smartech.gatech.edu/handle/1853/37090>
- Tew, A.E. & Guzdial, M. (2011). The FCS1: A language independent assessment of CS1 knowledge. *Proceedings of the 42nd ACM technical symposium on computer science education* (2011), 111–116. <https://doi.org/10.1145/1953163.1953200>

- Tirre, W. C., & Pena, C. M. (1993). Components of quantitative reasoning: General and group ability factors. *Intelligence, 17*(4), 501–521. [https://doi.org/10.1016/0160-2896\(93\)90015-W](https://doi.org/10.1016/0160-2896(93)90015-W)
- Tokowicz, N., & MacWhinney, B. (2005). Implicit and explicit measures of sensitivity to violations in second language grammar: An event-related potential investigation. *Studies in Second Language Acquisition, 27*(2), 173-204.
<https://doi.org/10.1017/S0272263105050102>
- Van Hell, J. G., & Tokowicz, N. (2010). Event-related brain potentials and second language learning: Syntactic processing in late L2 learners at different L2 proficiency levels. *Second Language Research, 26*(1), 43-74.
<https://doi.org/10.1177/0267658309337637>
- Vissers, C. T. W., Chwilla, D. J., & Kolk, H. H. (2006). Monitoring in language perception: The effect of misspellings of words in highly constrained sentences. *Brain Research, 1106*(1), 150-163.
<https://doi.org/10.1016/j.brainres.2006.05.012>
- Wang, Y., Kong, J., Tang, D., Zhuang, D., & Li, S. (2000). Event-related potential N270 is elicited by mental conflict processing in human brain. *Neuroscience Letters, 293*, 17–20.
[https://doi.org/10.1016/S0304-3940\(00\)01480-4](https://doi.org/10.1016/S0304-3940(00)01480-4)
- Weber-Fox, C. M., & Neville, H. J. (1996). Maturational constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers. *Journal of Cognitive Neuroscience, 8*(3), 231-256.
<https://doi.org/10.1162/jocn.1996.8.3.231>
- Webb, N. M. (1985). Cognitive requirements of learning computer programming in group and individual settings. *AEDS Journal, 18*(3), 183–194.
<https://doi.org/10.1080/00011037.1985.11008398>
- Wheelwright, S., Baron-Cohen, S., Goldenfeld, N., Delaney, J., Fine, D., Smith, R., Weil, L., & Wakabayashi, A. (2006). Predicting Autism Spectrum Quotient (AQ) from the Systemizing Quotient-Revised (SQ-R) and Empathy Quotient (EQ). *Brain Research, 1079*(1), 47–56.
<https://doi.org/10.1016/j.brainres.2006.01.012>
- Wray, S. (2007). SQ Minus EQ can predict programming aptitude. *Proceedings of the PPIG 19th Annual Workshop*, 243-254. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.222.8951&rep=rep1&type=pdf>
- Xie, B., Davidson, M. J., Li, M., & Ko, A. J. (2019). An item response theory evaluation of a language-independent CS1 knowledge assessment. *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, 699-705.
<https://doi.org/10.1145/3287324.3287370>

References

- Xie, B., Loksa, D., Nelson, G. L., Davidson, M. J., Dong, D., Kwik, H., ... & Ko, A. J. (2019). A theory of instruction for introductory programming skills. *Computer Science Education*, 29(2-3), 205-253. <https://doi.org/10.1080/08993408.2019.1565235>
- Xie, B., Nelson, G. L., Akkaraju, H., Kwok, W., & Ko, A. J. (2020). The effect of informing agency in self-directed online learning environments. *Proceedings of the Seventh ACM Conference on Learning@ Scale*, 77-89. <https://doi.org/10.1145/3386527.3405928>

