

Evidence for Reflective Abstraction: Seeing (Eye-Tracking Data) is Believing

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76 volunteering students aged 9-14 participated in a design-based research study investigating relations between perception, action, and cognition in the context of evaluating an experimental activity for learning the mathematical topic of proportions. In individually administered task-based interviews, participants manipulated a touchscreen tablet, trying to solve a micro-choreography problem involving a “mystery” bimanual coordination. Interface interactions were logged, all screen actions and multimodal utterance were videotaped, and eye-gaze pathways were recorded. For data analysis, eye-tracking pathways were superimposed onto the video data, so we could see where the participants were looking as they moved the virtual objects on the screen. To our surprise, concurrent with improved performance new eye-gaze path patterns emerged that were either static or dynamical but included screen locations bearing no apparent stimuli. Verbal and gestural input suggests that these spontaneous patterns served the participants as “steering wheels” for enhancing their control of the environment. We submit that the process of students exploring, discovering, and articulating these “steering wheels” bears a striking correspondence to Piaget’s hypothetical process of reflective abstraction: interiorization, coordination, encapsulation, and generalization. This study is perhaps the first to go beyond clinical data so as to corroborate a theoretical construct key to Piaget’s genetic epistemology.

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It was hardly our intention, when we embarked on a design-research study of proportional reasoning, to make a case for revitalizing Piagetian research on conceptual development. Rather, we were looking to investigate the interplay of perception, action, and cognition as children devise solutions for a touchscreen tablet bimanual manipulation task.

In this task, the user is required to figure out some motor-action coordination – a way of simultaneously moving two virtual objects on the screen, so as to satisfy the objective of maintaining a particular goal state, namely keeping a green feedback. The device has been set up so that the only way of getting the green feedback is by positioning the virtual objects at respective distances from a datum line such that the two distances correspond to an unknown ratio. For example in the Parallel condition and under the 1:2 ratio setting, an iPad is oriented vertically (portrait) with the cursors initially lying at the bottom of the screen, and the user must raise both cursors such that the right-hand cursor is consistently double as high from the bottom as compared to the left-hand cursor. In the Orthogonal condition and again under the 1:2 setting, the iPad is oriented horizontally (landscape) two cursors initially lie at the origin (the bottom left corner of the screen), and the user moves the left hand along the y -axis while moving the right hand along the x -axis. Here the right hand must be double as far from the origin as compared to the left hand.

This device is called a Mathematical Imagery Trainer. It was designed to create opportunities for children to learn how to move in a new way and then describe this new way of moving by means of using mathematical frames of references that are later introduced into the task environment. The project began in the Fall of 2008, and this way of learning has been evaluated in various settings and using a variety of interactive media with natural user interfaces.

And yet this paper is not about what one usually thinks of as mathematics learning, at least it is not about children engaging in the solution of assessment items involving verbal descriptions of problematic situations and algorithmic manipulation of symbolic notation. Rather it is about what, we speculate, is the meaning of mathematical concepts. That is, the paper is about sensorimotor schemes oriented on new phenomenal categories. We believe we are seeing in our empirical data evidence for the formation of new schemes and categories. That is, we believe we are seeing in our data evidence supporting Piaget's conjecture that new higher-order schemes begin from the coordination of simpler schemes. The objective of this presentation is to share some of the data visualizations that encouraged us to make these tentative claims. If we are correct, then this might be the first visual demonstration ever of the micro-process of mathematical ontogenesis.

A key element of our research design that is enabling us to pursue this line of argumentation is the inclusion of eye tracking as part of the manifold of real-time data we

collect as the child engages in the tablet work. This technology in its various historical guises is hardly too new in and of itself, however the particular context in which we apply this technology might be: By way of knowing where children are looking, and in triangulation with audio-video data, we can infer what new objects the children are constructing.

By objects we here refer to features or constellations of features of a visual display – bearing either actual perceptual stimuli, imaginary stimuli, or both – that the child conjures into the task environment as their apparent means of facilitating the enactment of an otherwise overwhelming motor-action coordination. These new objects serve as a “steering wheel” or immaterial tool that the child applies to the environment.

The metaphoric notion of new phenomenal categories serving as a “steering wheel” derives from systemic perspectives on motor-action learning and control, and in particular discussion of order parameters, aspects of enactment that optimize performance efficiency (Kostrubiec, Zanone, Fuchs, & Kelso, 2012; Newell & Ranganathan, 2010). A converging theoretical resource for our work is the literature from ecological psychology, a blend of dynamical systems theory and ecological psychology originating in sports sciences and kinesiology (Chow et al., 2007). Hutto and Sánchez-García (2015) worked within similar frameworks to develop the notion of an attentional anchor, an aspect of the agent-environment relation that agents tacitly develop to enhance their grip on the world. In turn, we have used this notion of an attentional anchor so as to explain the emergence of these perceptual patterns serving our study participants in improving their control of the Mathematical Imagery Trainer (Abrahamson & Sánchez-García, in press; Hutto, Kirchhoff, & Abrahamson, 2015; Shayan, Abrahamson, Bakker, Duijzer, & Van der Schaaf, 2015). This presentation puts a Piagetian spotlight on the attentional anchor, claiming that it embodies the new categories that children construct in the world, even as they develop new sensorimotor schemes for operating on these categories (Abrahamson, Shayan, Bakker, & Van der Schaaf, in press).

Our data come from the work of 76 volunteering students aged 9-14 who participated individually with an experimenter in a task-based semi-structured clinical interview. The task centered on operating a new version of the Mathematical Imagery Trainer developed at Utrecht University, which logged all actions. During data analysis, the researchers worked both “top down,” looking for eye-tracking evidence of some patterns we had detected in earlier studies (Abrahamson, Trninic, Gutiérrez, Huth, & Lee, 2011; Howison, Trninic, Reinholz, & Abrahamson, 2011) and “bottom up,” scouting for new patterns that we had not seen before.

The participants discovered a wide range of attentional anchors, which suggests the multiple cognitive entries afforded by the device. Concurrent with these spontaneous constructions, the participants’ performance became more efficient. Soon after, they reported in speech and gesture that they had figured out an effective way of controlling the screen.

We will draw implications for the theory and practice of mathematics education.

References

- Abrahamson, D., & Sánchez-García, R. (in press). Learning is moving in new ways: The ecological dynamics of mathematics education. *Journal of the Learning Sciences*.
- Abrahamson, D., Shayan, S., Bakker, A., & Van der Schaaf, M. F. (in press). Eye-tracking Piaget: Capturing the emergence of attentional anchors in the coordination of proportional motor action. *Human Development*.
- Abrahamson, D., Trninic, D., Gutiérrez, J. F., Huth, J., & Lee, R. G. (2011). Hooks and shifts: A dialectical study of mediated discovery. *Technology, Knowledge, and Learning*, 16(1), 55-85.
- Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araújo, D. (2007). The role of nonlinear pedagogy in physical education. *Review of Educational Research*, 77(3), 251-278.
- Howison, M., Trninic, D., Reinholz, D., & Abrahamson, D. (2011). The Mathematical Imagery Trainer: From embodied interaction to conceptual learning. In G. Fitzpatrick, C. Gutwin, B. Begole, W. A. Kellogg, & D. Tan (Eds.), *Proceedings of the annual meeting of The Association for Computer Machinery Special Interest Group on Computer Human Interaction: "Human Factors in Computing Systems" (CHI 2011), Vancouver, May 7-12, 2011* (Vol. "Full Papers", pp. 1989-1998). New York: ACM Press.
- Hutto, D. D., Kirchhoff, M. D., & Abrahamson, D. (2015). The enactive roots of STEM: Rethinking educational design in mathematics. In P. Chandler & A. Tricot (Eds.), Human movement, physical and mental health, and learning [Special issue]. *Educational Psychology Review*, 27(3), 371-389.
- Hutto, D. D., & Sánchez-García, R. (2015). Choking RECTified: Embodied expertise beyond Dreyfus. *Phenomenology and the Cognitive Sciences*, 14(2), 309-331. doi:10.1007/s11097-014-9380-0
- Kostrubiec, V., Zanone, P.-G., Fuchs, A., & Kelso, J. A. S. (2012). Beyond the blank slate: Routes to learning new coordination patterns depend on the intrinsic dynamics of the learner -- experimental evidence and theoretical model. *Frontiers in Human Neuroscience*, 6. doi:10.3389/fnhum.2012.00222
- Newell, K. M., & Ranganathan, R. (2010). Instructions as constraints in motor skill acquisition. In I. Renshaw, K. Davids, & G. J. P. Savelsbergh (Eds.), *Motor learning in practice: A constraints-led approach* (pp. 17-32). Florence, KY: Routledge.
- Shayan, S., Abrahamson, D., Bakker, A., Duijzer, A. C. G., & Van der Schaaf, M. F. (2015). The emergence of proportional reasoning from embodied interaction with a tablet application: An eye-tracking study. In L. Gómez Chova, A. López Martínez, & I. Candel Torres (Eds.), *Proceedings of the 9th International Technology, Education, and Development Conference (INTED 2015)* (pp. 5732-5741). Madrid: IATED.