Chapter 3
An Embodied/Grounded Cognition Perspective on Educational Technology

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Students typically learn in school in ways that are disconnected to their own experience, and so they learn to know about subject areas rather than have a feel for them. Thus, what they learn in school becomes stored in memory as abstract symbolic knowledge that is not connected to their experience in the world, so they do not think to apply it in their everyday life (or other contexts) when it might be appropriate. For example, students learn physics formulas in school that they practice applying to problems in their physics courses, but they do not understand the implications of these formulas for how they reason about the physical dynamics of the real world. Similarly they learn formulas for solving statistics problems in school but that does not affect the way they reason about uncertain or statistical phenomenon that they encounter in other contexts. The problem is that the students do not have a body of perceptual experiences that they draw upon when learning this new subject matter for they only learn about the subject matter rather than also develop a feel so it. Recent basic cognitive research in perceptually grounded or embodied cognition provides a framework for understanding this distinction and for designing educational environments that foster this deeper level of understanding.

Grounded/Embodied Cognition

Perceptually grounded or embodied cognition is an increasingly prominent area of basic cognitive research (Barsalou, 2008). This perspective says that a full understanding of something involves being able to create a mental perceptual simulation of it when retrieving the information or reasoning about it. Both behavior and neuroimaging experiments have shown that many phenomena that were thought to be purely symbolic actually show perceptual effects. For example, property verification (e.g., retrieving the fact that a horse has a mane) was thought to involve a search from a concept node (horse) to a property node (mane) in a symbolic propositional network and thus the time to answer and errors were determined by how many

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network links needed to be searched and how many other distracting links were present. However, grounded cognition research has shown that perceptual variables like size (e.g., the bigger the property to be retrieved the faster) affect verification times and errors (Solomon & Barsalou, 2004). Also, neuroimaging results (e.g., fMRI) show that perceptual areas of the brain (involving shape, color, size, sound and touch) also become active during this task, not just the symbolic areas (e.g., Martin, 2007). Thus, if one is familiar with horses and manes then doing even this simple property verification involves a perceptual simulation.

Even text comprehension shows spatial (perceptual) effects. For example a switch in point of view in a narrative creates longer reading times and more memory errors because the reader has to switch the spatial perspective from which they are viewing the narrative scene in their imagination. For example

> John was working in the front yard then he went inside

is read faster than with a one word change that switches the point of view (Bower, Black, & Turner, 1979):

> John was working in the front yard then he came inside.

Thus, when reading even this brief sentence the reader is forming a simple spatial layout of the scene being described and imaging an actor moving around it—i.e., this is a simple perceptual simulation.

Glenberg, Gutierrez, Levin, Japuntich and Kaschak (2004) have shown how to teach reading comprehension using a grounded cognition approach. Specifically, these studies found that having 2nd grade students act out stories about farms using farmers, workers, animals and objects increased their understanding and memory of the stories they read. Further, if they also imagined these actions for another related story after acting it out with toys, they seemed to acquire the skill of forming the imaginary world of the story (Black, 2007) when reading other stories, and this increased their understanding and memory of these stories. Thus, this grounded cognition approach increased the students' reading comprehension. These studies also seem to indicate that there are three steps involved in a grounded cognition approach to learning something:

1. Have a perceptually grounded experience
2. Learn to imagine the perceptually grounded experience
3. Imagine the experience when learning from symbolic materials

Gaining Embodied/Grounded Experiences from Video Games

Hammer and Black (2009) showed that video games can serve to create perceptually grounded experiences that can serve to increase later symbolic learning and understanding. Specifically, they found that expert players of the *Civilization* historical simulation game did not show any superior knowledge of the history covered in the game compared to expert players of another academically oriented game (*Sim City*), so they did not seem to learn much about history directly from playing the game.

However, when given a college textbook chapter about a related historical topic that was not covered in the game they were able to learn much more from that chapter than the expert players of the comparison game—and they were able to learn facts, images, procedures and systems knowledge better. Thus, the grounding experiences of grappling with historical issues in the Civilization historical simulation game prepared the expert players for future learning from the formal symbolic task of reading a college history textbook chapter (Bransford & Schwartz, 2001). This result also fits with Dewey's (1938) stress on the importance of having related experiences when trying to learn something new; these experiences provide the needed perceptual grounding need for the symbolic learning to make sense.

Similarly, Ahn (2007) found that college business school students' experiences in playing an entrepreneurship business game yielded the best learning and understanding when combined with a more formal symbolic learning experience that involved contemplating the strategies used in the game and relating those strategies to background readings in the course. Here again, the experiences provided from playing the entrepreneurship business game (several times in this case) provided the grounding needed to learn more from the college course readings.

Learning from Graphical Computer Simulations with Movement and Animation

In learning a mental model for a system, students need to learn and understand the component functional relations that each describe now as a system entity changes as a function of changes in another system entity. Chan and Black (2006) found that graphic computer simulations involving movement and animation were a good way to learn these functional relations between system entities. For example, the roller coaster graphical computer simulation shown in Fig. 3.1 allows students to learn the functional relation between the height of the roller coaster cars in the gravity field and the kinetic and potential energy by having students move the slider at the bottom of the screen to move the roller coaster cars along the peaks and valleys of the track and simultaneously see the resulting changes in kinetic and potential energy shown in the animation of the bar graph changes. Thus one variable (the height in the gravity field) is directly manipulated by movement (of the student's hand and mouse) and the other two variables (kinetic and potential energy) are shown by animated changes in the bar graph.

The direct manipulation animation version of the simulation was compared to other versions involving just text, text and pictures (screen shots of the simulation), and a "slide show" showing screen shots, and the more grounded/embodied direct manipulation animation version yielded the best memory, problem solving and transfer problem solving to another context. Further research has shown that for simple systems (e.g., a swing instead of a roller coaster), text and text-plus-diagrams are sufficient for 6th grade students to master the system, but 5th grade students do better with the direct manipulation animation. For more complex systems (e.g., a pole vault instead of a roller coaster) both 5th and 6th grade students needed a direct

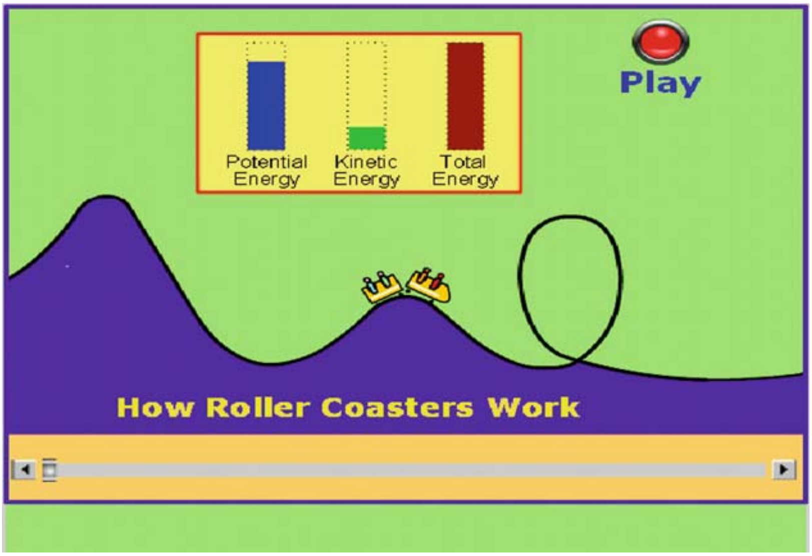

Fig. 3.1 Roller coaster graphic simulation with movement (mouse and slider) and animation

manipulation animation for best memory, problem solving and transfer. It seems likely that the students are learning to imagine perceptual simulations in all cases (although one would need a neuroimaging study to know for sure, and such studies are planned) but that the learning materials needed to enable this imagined simulation vary depending on the complexity of the system and the cognitive development (grade level in this case) of the students.

Han and her colleagues (Han, Black, Paley, & Hallman, 2009; Hallman, Paley, Han, & Black, 2009) have enhanced the movement part of these interactive graphical simulations by adding force feedback to the movement using simulations such as that shown in Fig. 3.2. Here the student moves the gears shown in the middle by moving the joy stick shown in the lower left, and the bar graphs show the input and output force levels for the two gears; here again allowing the student to directly manipulate the gears enhances the students' memory and problem solving, and enriching the movement experience by adding force feedback increases the students' performance even more. Thus the richer the perceptual experience, and therefore the mental perceptual simulation acquired, the better the student learning and understanding.

McVeigh, Black, and Flimlin (2008) showed that even when the learning experience is fully embodied using hands-on activities adding these kinds of interactive graphic simulations can enhance student learning and understanding. Here the students learn about water chemistry and fish and plant biological systems by having a small fish tank in their classrooms while also observing a larger fish tank (using a video link over the internet) in a large remote greenhouse located at a local university. Thus the students can directly alter the water chemistry in the classroom fish

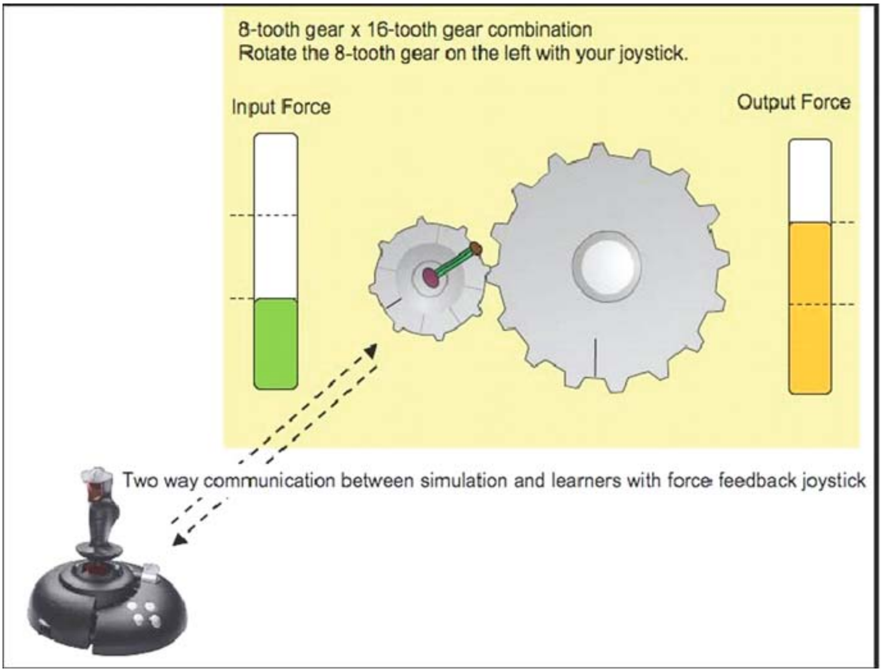

Fig. 3.2 Gear graphic simulation with movement (joystick and gears) and animation with force feedback (joystick)

tank and also in the large remote one by a controlling robot arm. Thus, this situation provides considerable embodiment, but student learning and understanding was increased when a graphic computer simulation was added for the fish tank where the student could directly manipulate the variables involved (e.g., the temperature of the water) and observe animations of the results on other components of the fish tank ecology. The interpretation of these results is that the graphical computer simulation involving movement and animation helped the students form the mental grounded perceptual simulations that they need for better learning and understanding.

Creating Video Games to Embody Understanding

In the Teachable Agent (TA) project (Schwartz, Blair, Biswas, Leelalong, & Davis, 2007) and the Reflective Agent Learning (REAL) environment project (Bai & Black, 2010) students learn by specifying what their agents know in a video-game-like virtual world, then get feedback by how well their agents do in the virtual world with the knowledge the students have given them. In the TA project, agent Betty is given knowledge about something like river ecology by the students studying that topic and then drawing a concept map that gives both propositional relations (e.g., fish have gills) and system functional relations (e.g., increasing the number of plants increases the amount of oxygen). Based on this concept map, Betty can then answer questions or fail to be able to answer them, and she can be compared with other agents who were provided knowledge through concept maps by other students using a TV quiz-show-like virtual world. The research with TAs shows that students learn more this way than with other instructional methods—including just doing concept maps without the agent cover story. There is even a "protégé effect" (Chase, Chin, Oppezzo, & Schwartz, 2009) where the students will work harder to try to give their agent good concept map knowledge than they will to prepare themselves for the quiz show (i.e., they want their agent "protégé" to perform well).

In the REAL Business project (there are different versions of REAL for different content areas) shown in Fig. 3.3, the students learn some simple statistics by using procedural networks to specify what an agent running an ice cream shop knows that will enable him to order the right amount of each ice cream flavor based on prior experiences with customer agents that flow through the ice cream shop (doing well involves knowing about statistical sampling). REAL Planet is another version of REAL that involves ecological knowledge similar to the TA project, although in the REAL case the agents move through the virtual world and interact with it. REAL does not yet have any research results on student learning and understanding, but its research results seem likely to be similar to the TA results. In both the TA and REAL projects, student learning and understanding is increased by being able to embody their understanding in animated agents (their "protégés") in virtual worlds and then try out and revise their knowledge based on their agents' performances in the virtual world.

Recently Fadjo and colleagues (Fadjo, Hallman, Harris, & Black, 2009) have been exploring using the simpler *Scratch* programming language from the MIT

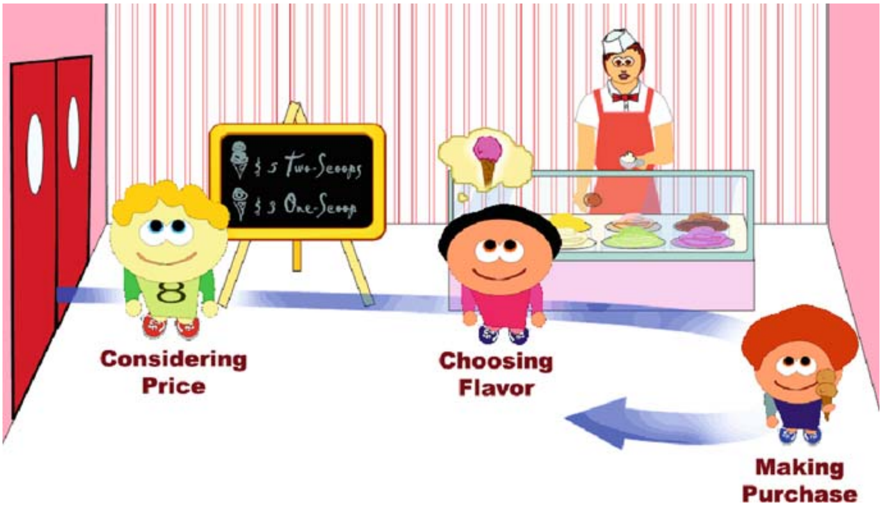

Fig. 3.3 REAL (reflective agent learning environment) business involving specifying decision procedures for Manager Agent to order ice cream for customer agents

Media Lab to have students in elementary and middle school program simple video games to embody their understanding of something in the agents in those video games. Scratch is a computer programming language that tries to teach programming through video game construction. Initial results indicate that having students act out agent actions using their own bodies (a real embodied experience) then programming the virtual agents to do the same thing (a virtual embodied experience) is a particularly effective learning approach. Other recent work is trying to do the same thing by programming robots to move around in and interacting with the real world (instead of a virtual world) to embody and test the student understanding (Li, Kang, Lu, Han, & Black, 2009).

Conclusions

Recent basic cognitive research and theory in perceptually grounded or embodied cognition provides a framework for considering how we can deepen and increase student learning and understanding by having them develop a "feel" for what they are learning in addition to knowing about it. Used in ways guided by this theoretical framework, video game playing together with more formal learning, interactive graphic computer simulations involving movement and animation (and force feedback), video game programming and robot programming can be used to increase student learning and understanding.

References

Ahn, J. (2007). Application of experiential learning cycle in learning from a business simulation game. Doctoral Dissertation, New York: Teachers College, Columbia University.

Bai, X., & Black, J. B. (2010). Enhancing intelligent tutoring systems with the agent paradigm. In S. Stankov, M. Rosov, and V. Glavinic (Eds.), *Intelligent tutoring systems in eLearning environments: Design, implementation and evaluation* (pp. 195–218). Hershey, PA: IGI Global Publishing.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645.

Black, J. B. (2007) Imaginary worlds. In M. A. Gluck, J. R. Anderson, & S. M. Kosslyn (Eds.), *Memory and mind*. Mahwah, NJ: Lawrence Erlbaum Associates.

Black, J. B., Turner, T. J., & Bower, G. H. (1979). Point of view in narrative comprehension, memory and production. *Journal of Verbal Learning and Verbal Behavior*, *18*, 187–198.

Bransford, J., & Schwartz, D. (2001). Rethinking transfer: A simple proposal with multiple implications. In A. Iran-Nejad & P. D. Pearson (Eds.), *Review of research in education* (Vol. 24, pp. 61–100). Washington, DC: American Educational Research Association.

Chan, M. S., & Black, J. B. (2006). *Direct-manipulation animation: Incorporating the haptic channel in the learning process to support middle school students in science learning and mental model acquisition*. Proceedings of the International Conference of the Learning Sciences. Mahwah, NJ: LEA.

Chase, C., Chin, D. B., Oppezzo, M., & Schwartz, D. (2009). *Journal of Science Education and Technology*.

Dewey, J. (1938). *Experience and education*. New York: Touchstone.

Fadjo, C., Hallman, G. Jr., Harris, R., & Black, J. (2009). *Surrogate embodiment, mathematics instruction and video game programming*. In Proceedings of world conference on educational multimedia, hypermedia and telecommunications 2009 (pp. 2787–2792). Chesapeake, VA: AACE.

Glenberg, A. M., Gutierrez, T., Levin, J. R., Japuntich, S., & Kaschak, M. P. (2004). Activity and imagined activity can enhance young children's reading comprehension. *Journal of Educational Psychology*, *96*, 424–436.

Hallman, G., Paley, I., Han, I., & Black, J. (2009). *Possibilities of haptic feedback simulation for physics learning*. In Proceedings of world conference on educational multimedia, hypermedia and telecommunications 2009 (pp. 3597–3602). Chesapeake, VA: AACE.

Hammer, J., & Black, J. (2009). Games and (preparation for future) learning. *Educational Technology*, *49*, 29–34.

Han, I., Black, J., Paley, I., & Hallman, G. (2009). Feel, imagine and learn: Learning from visual and haptic simulations. *Subway Summit 2009*. New York: Fordham University.

Li, D., Kang, S., Lu, C., Han, I., & Black, J. (2009). *Case studies of developing programming skills via embodied experiences in an after-school LEGO Robotics Program for elementary school students*. In Proceedings of world conference on educational multimedia, hypermedia and telecommunications 2009 (pp. 2209–2216). Chesapeake, VA.

Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology*, *58*, 25–45.

McVeigh, D., Black, J., & Flimlin, G. (2008). How system simulations improve student learning by assisting in the creation of clear mental models. In K. McFerrin et al. (Eds.), *Proceedings of society for information technology and teacher education international conference 2008* (pp. 1767–1773). Chesapeake, VA: AACE.

Schwartz, D., Blair, K., Biswas, G., Leelawong, K., & Davis, J. (2007). Animations of thought: Interactivity in the teachable agents paradigm. In R. Lowe & W. Schnotz (Eds.), *Learning with animation: Research and implications for design*. UK: Cambridge University Press.

Solomon, K., & Barsalou, L. (2004). Perceptual simulation in property verification. *Memory and Cognition*, *32*, 244–259.