Episode 22: The Amazing Declarative to Procedural Transition

Show Notes

Big changes happen in memory and knowledge as a person goes from beginner to expert. What does this entail for playing games? We take a close look at the two main types of memory, and how knowledge transitions between the two.

Game References

Marvel's Spider-Man, Secret Cabal of Gaming

Research References

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Transcript

Hello! This is Episode 22 of the Cognitive Gamer podcast. I am your host, Steve Blessing, a professor of cognitive psychology at the University of Tampa. I use games to both explain and explore how we think. I hope you all had a relaxing end to 2018 and a good start to 2019. I'm looking forward to another year of Cognitive Gamer podcasts in which we look at the intersection of psychology and playing games. In this episode we are going to take a deeper dive into something I touched upon back in Episode 11, where I laid out a general roadmap about how human memory and knowledge works. Don't worry if you haven't listened to that one, I'll give us enough background on the particular topic to get started.

The big idea behind Episode 11 was to provide a brief description of how cognitive psychologists divide up human knowledge and memory into its different types. Most people are aware of shorter term memories versus longer term memories, but cognitive psychologists make finer distinctions than that. In Episode 11 I talked about declarative memories versus non-declarative memories, and it's this distinction I would like to talk about here, particularly how knowledge transitions from one of these types to another.

Declarative memories are pretty straight-forward, because the name kind of gives away what they are all about. This is knowledge that you can easily talk about, or declare. The last game night that you had, the rules to your favorite game, playing dungeons and dragons in your parent's basement as a preteen, these are all declarative memories. This knowledge is acquired through our senses, through what we see, hear, taste, smell, and feel. For some of these memories, we can close our eyes and play them back, such as that last game night you had. These types of declarative memories are referred to as episodic, because they are episodes of our life, having a particular time and place associated with them. Other declarative memories that we can easily talk about, like the rules to a favorite game, don't have that time and place information associated with them, and so are often referred to as semantic. That is, you know them, but you don't remember learning them. Your knowledge of basic arithmetic facts are also like that, like what's two plus two. You all know that, learned it sometime ago, can easily recite it, but probably have no idea when or where you learned it. I'm not going to dwell too much on this episodic versus semantic distinction in this podcast, and indeed cognitive psychologists will spar on whether these are truly qualitatively different types of declarative memories or if they just vary as to degree. But for our purposes now, that argument can be had another on a later podcast.

I referred to the other main type of knowledge that we have as non-declarative. If that sounds mostly like it's being used as a catch-all for anything that's not a declarative memory, you're right! Cognitive psychologists definitely disagree as to how to divide memory in general, but this particular division is a challenging one. Non-declarative is the label that's used in many intro to psychology textbooks. I'm going to be very specific in what I mean by it, and I will call it procedural memory. With this distinction, when I talk about memory in class, I often refer to declarative memory, what we talked about previously, as your knowledge of "what" things are, and then this other type of memory, procedural knowledge, as your knowledge of "how" to do things. Procedural knowledge then covers your ability to navigate an environment in a first- or third-person shooter using either a mouse and keyboard or a controller, how to give an awesome clue in Codenames, and how to re-arrange your Scrabble tiles into the best word. Sure, you can talk about all that and teach it to someone verbally, that is, declaratively, but it's probably more you doing the action and then reporting back what you observe yourself doing. The origin isn't a declarative knowledge store, but rather procedural, particularly if these are skills that you have done for a while. Your ability to talk about it is post hoc. You've probably observed that when you do try to talk about procedural knowledge, you find it either very hard to do or it slows you down. Or, perhaps both. When you do this, it truly does have this aspect of you observing yourself, and then describing those actions that you've already done or are about to do.

In Episode 11, I talked about some of the experimental evidence for these two types of memory. I discussed the neurological findings from amnesiac patients, those with damaged brains, that can learn one type of memory but not the other. What I would like to do today is to talk more about this transition from declarative memory to procedural memory. This discussion is informed very much by a particular theory of cognition, the John Anderson's ACT Theory of cognition. He was my PhD thesis advisor at Carnegie Mellon, so while there may be a little self-interest here, John truly is one of the greats in cognitive science, and his ACT Theory one of the most well-respected and well-rounded unified theories of cognition out there. I encourage you to take a look and not just take word for it! I'll put a link or two in the show notes to get you started.

One strong claim of the ACT Theory is that all memories start at in the declarative store and transition to procedural with practice. Indeed, that was the particular issue I examined in my doctoral dissertation, really hitting that process as it existed in an earlier version of the theory. You may be interested to know that the ACT Theory is fully substantiated enough that there's a computer version of it, that has gone through several iterations. They are now at version 7, it was at version 4 when I did my PhD work 20 or so years ago. That means that you can create a computer model of these cognitive processes, not only for memory but also lower level processes like perception and higher-level processes like problem solving and decision making. For those truly interested, anyone can download the software from the ACT website, along with a tutorial. From these computer models you can either model past human data or create predictions for future experiment done with humans. If the model can predict performance, that gives you confidence that the model has validity. What goes on in both declarative and procedural memories is something that has had been modeled extensively with the ACT Theory and software. As an aside, the ACT Theory is referred to as a symbolic architecture, contrasted with the subsymbolic architure of neural networks that get a lot of attention the press and science fiction novels. The subsymbolic architecture of neural network attempts to mimic more closely how the human brain works, as we can see how real-word examples of these like Alexa and AlphaGo have made great strides. Symbolic architectures like the ACT theory abstract over the minute details that happen in neural networks and use as their primitives objects and symbols, that have more meaning. I'll talk about these next.

I told you previously that declarative memories all start out by what comes through our 5 senses: seeing, hearing, feeling, tasting, and smelling. That makes sense, pun intended, because, that's how we experience the world, and we can talk about those experiences. These memories are obviously quite useful, and they are very flexible. They can be used in a variety of instances. Your knowledge of math facts can be used in a whole host of different types of games, from tabulating victory points to scores, to hit points, to wherever you have to add, subtract, multiply, or divide. Also, you can talk about something like the last game you played and whether you liked it or not to your best friend while talking on the phone, in a review you are writing, or while at a game store. This flexibility though comes at a bit of a cost, in terms of speed to access and use. Sure, you can practice those types of memories and will they be accessed and used more quickly, but never as efficiently as what a procedural memory can be.

Procedural memories are specialized for the way in which the knowledge is used. I won't get too technical here, but in the ACT architecture declarative knowledge is represented as chunks, that's the actual term, of related information. Again, that's a very flexible representation. Procedural knowledge is represented as productions, these are condition-action pairs, or if you're a programmer, a slightly more complicated if-then statement. They essentially take the form of a condition, that is "If this is true about the situation" then take this action, and the action will change the current situation into something else. And to be clear, your declarative knowledge is part of the situation as well. To do any interesting action, like even play a simple game such as Tic-Tac-Toe requires a whole sequence of productions to work together. One of them might be "If I am playing Tic-Tac-Toe, and it's my turn, and no square has been chosen, then put an 'X' in the center square." A set of productions that accomplishes some task is simply called a production set. In a previous job I used to work on software called cognitive tutors that a student would use to learn a new subject, like Algebra I. The tutors were effective because they based their instruction on a cognitive model of the skill, realized as a production set. The production set for Algebra 1 had a few thousand productions in it. The advantage of a production is its efficiency, it will execute quickly. It's quick though because it will only change the state of the current situation, to "fire" is the technical term, if the condition matches the current situation. If anything is off, it probably won't fire. I can imagine writing an ACT model to play a game, like Catan or Scythe or Terraforming Mars, and it might be on the order of several hundred production rules.

Let's quickly discuss how new procedural memories are formed. Again, I don't want to get too much into the weeds, but there are two different ways. Totally new procedurally memories can be formed by analogizing two declarative memories together. If there are two things that are similar out in the world, it may make sense to convert them into more efficient memories. Codenames and Decrypto have certain similarities, but also differences as I discussed in Episode 19. As you notice these similarities and differences, you may create procedural knowledge to assist you in your play, something like "If playing a word game, and I need to give a clue, and these two words are related in this way, then give a clue based on that relation." Again, that's very high level and would probably need to actually be substantiated in dozens of actual productions. This is essentially what I did in my dissertation, looking at this process of creating productions based on analogy, not in a game context but in learning something like algebra. The other way new productions can come about is through a process called compilation; if two productions always or often occur together, then instead of chaining the first production with the second, to speed things up even more you can essentially compile these two together by creating a new third production by combining the condition of the first production with the action of the second production. If that turns out to be truly useful then this third production will gain strength and will be used more than the two productions separately.

This process of creating new declarative knowledge by interacting with the world and then proceduralizing it as we gain experience within the domain accounts for how we acquire any cognitive skill, including games as well as academic knowledge, sports, learning a musical instrument, and anything else. Indeed, sometimes as we transition from using declarative knowledge to perform an action to where it's mostly procedural, that declarative knowledge will fade away due to lack of use. Here's a quick example, I'm going to ask you a simple question, answer as quickly as you can: where is the letter 'e' at on the typewriter keyboard? Okay, how many of you noticed that you moved the middle finger of your left hand to help you answer? Probably a clear majority, as it is in most of my classes. Knowledge of typing starts out declaratively, but quickly becomes proceduralized, such that to answer that question you need to do the action in order to answer it. The same thing would happen if I ask PS4 users which direction the triangle is or Xbox players which direction the X button is. I saw that thumb move!

This process has been brought clearly to my mind the last couple of weeks. I finally started playing Marvel's Spider-man for PS4. I'm several hours in at this point, having just completed the first act. I'm loving it by the way. But I was a mess at the beginning! To get swinging, you need to hit X to jump, then press R2 and keep holding to shoot out a web, and when you're close to the top of your swing, release R2 and press it again. You can also press X or do both R2 and L2 together to help get you to point to point. And that's just swinging. Fighting is a whole other story. There's all these different combos of the buttons to get you leaping, hitting, slinging and dodging in different directions. At first I thought this was never going to come together. For swinging and fighting I had to think very deliberately about what needed to be done. I was slow. I was using declarative knowledge. But, that declarative knowledge became proceduralized as I went along. I should be very explicit here, this transition from declarative to procedural memory is not a conscious process on your part; it just happens as your practice. Your mental machinery does all that work without you being aware it's happening. As my cognitive processes did their thing, I became not only better, but also faster. When fighting Fisk's men and the Demon gang I have become much more efficient in my moves and don't have to think about the buttons to press nearly as much, until I unlock a new gadget or fighting capability to add to my repertoire.

To give you a pointer to another example of this process, the guys over at the Secret Cabal of Gaming recently released one of their express episodes that directly relates to this. In Express Episode 44 from January 4 of this year, Bender, Aaron, and Jamie discuss painting miniatures to be used in tabletop and RPG games. Their whole conversation is about the declarative knowledge you need to assemble, prime, paint, and finish the miniatures. They talk about the tools and tips they have used during the many months and years they have devoted to the hobby. That's all declarative memory. But, as they talk, you also get a good sense of how some amount of those memories and knowledge have been proceduralized as they have gotten more experience. I encourage you to listen to that episode, not only to learn a bit about painting miniatures, but also to appreciate this transition from declarative to procedural knowledge that you can probably now pick up on as they discuss this domain.

One thing that follows from this is what you've probably heard of as "the learning curve." Simply put, you get better at a task the more you do it. That's evident in both my Spider-Man example and the Secret Cabal of Gaming talking about miniature painting. In cognitive psychology, we refer to it more fully as the power law of learning, though some argue it's really more exponential. Regardless, because learning almost any skill follows one of these functions, an actual mathematical formula with very regular features can be used to plot it. Again, I'll put a reference in the show notes if you want the details, but in general, these curves, if you're plotting something like number of attempts on the x-axis and time to play a game or perform an action on the y-axis, or perhaps you plot errors on the y-axis, you see a steep drop off early in the curve, but that with more experience there's less increase in learning, or fewer errors, but there still is improvement. The curve does asymptote, but that's the point of asymptotes; they only get there at infinity. There's a classic study done by Crossman in 1959 that shows that cigar rollers, even after 7 years of experience which is on the order of about 10 million cigars rolled according to the article, still shows signs of improvement. There are still efficiencies of knowledge and skill to be had after that long tail of practice. My wife is now shuddering of what should happen if I practiced traversing New York City in Spider-Man for 7 years.

I'll give both a board game example and a video game example of this as well. In board games, think about your favorite medium or heavier weight game, something like Scythe or Terra Mystica. Think about the first you and your board game group played it and how long it took. A couple of episodes ago my wife and I discussed when we played Scythe for the first time. Even after having played My Little Scythe and watched Rodney Smith teach it, it still took 3 hours to get through the game. But, we had a lot of declarative knowledge to sort through, learn, and figure out, and little to no procedural knowledge. I am confident the second time we play it will take much less time, and the third time even a little less. We'll be working our way down the power law of learning.

To give a video game example, think about people who do speed runs in these games. These are people who devote countless hours honing how best to finish a game in the shortest amount of time. I'm sure their practice and performance, in large part, has been governed by the power law of learning. Their first time through it took an average amount of time for them to complete their game. But then they keep doing it, with subsequent attempts taking less and less, with all that knowledge re-organizing itself to where it is after 100s of hours playing the game, mostly, if not almost entirely, in a proceduralized state. Some of them probably are at the practical limits of how fast you can get through the game. The 2019 Games Done Quick benefit has just concluded, with several of the best speed runners using their talents to benefit charity. I encourage you to look at the Games Done Quick website or search for the videos on YouTube to look at these people who are low, low down on the learning curve.

Let's let that bring us to a close on the transition from declarative to procedural knowledge and memory. I encourage you to think about this information as you learn a new task. Maybe the next time you start to learn a new game, think about all the declarative knowledge you are picking up, maybe how it seems a bit overwhelming, but then overtime how your performance at the task gets better and better as that knowledge becomes better rehearsed and proceduralized. There are still some things to talk about in this area, such as getting about more into the pros and cons of having expert knowledge encoded in terms procedures. Obviously you get expert performance that way, but you also get some interesting downsides like functional fixedness and something called Einstellung. But, those will be topics we'll examine more closely later.

As always, I welcome any comments or questions you may have, so please email me, steve@cognitivegamer.com and also visit my website, cognitivegamer.com. Also, you can like me on Facebook, Cognitive Gamer, or follow me on Twitter, @cognitive_gamer.

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