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Cognitive Apprenticeship: Teaching Students How to Think Like an Expert

David Gomillion
dgomillion@mays.tamu.edu

Jordana George
jgeorge@mays.tamu.edu

Aaron Becker
abecker@mays.tamu.edu

Michael Scialdone
mscialdone@mays.tamu.edu

Information and Operations Management
Mays Business School
Texas A&M University
College Station, Texas

Abstract

Cognitive Apprenticeship is an adaptation of the traditional model of education where apprentices would gain skills by working with an expert over time. This form of education is still practiced today in highly complex fields like law and medicine, as well as in technical fields like plumbing and electrical work. The same attributes of apprenticeship that make traditional forms successful can be applied to problem-solving, critical thinking, and other high-level skills. This paper explores how cognitive apprenticeship can be applied to a Systems Analysis and Design course to teach problem-solving and critical thinking.

Keywords: Cognitive Apprenticeship, Self-Efficacy, Behavioral Controls, Teaching Experience.

1. INTRODUCTION

When we teach, we are asking our students to trust us. The goal of teaching is to change how students think: how they see the world, how they respond to that world, and how they behave to try to change the world (Eisner & Vallance, 1974). However, changing thinking is not an easy or comfortable process for people. And so we ask students to trust that what we are doing will indeed benefit them. We are asking them to take leaps of faith every day in the classroom, and every evening they do homework.

Even with the clearest course objectives with holistic support, students have varying levels of success in achieving the goals we set. While course objectives serve as the measuring stick of what students should be able to know or do, every class has pupils that fail to thrive. Some may not engage with the material at a level sufficient to grasp fully the requisite skill or required knowledge. Others just seem to miss the big picture. Still others see the big picture but cannot achieve success without constant guidance. While motivation is primarily the responsibility of the student, and faculty have limited resources to fully engage every student, there are some small steps that faculty can take

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to better reach all students. One such approach that can improve learning is cognitive apprenticeship (CA). CA is a teaching technique that trades lectures for hands-on practice in class with instructure guidance (Collins, Brown, & Newman, 1988; Dennen & Burner, 2008).

Apprenticeship was the key model of teaching and learning until the last century. It has one key benefit over current education models: it "embeds the learning of skills and knowledge in the social and functional context of their use" (Collins et al., 1988, p. 1). This eliminates the common refrains of students such as "when will I ever use this" or "what will it be like when I get out into the real world." Students experience knowledge in its real-life context rather than the abstracted forms we often teach in the classroom. The point that Collins et al (1988) makes is that such apprenticeship does not have to be limited to only hands-on technical tasks; instead, it can be leveraged to teach people reading, writing, and mathematics. In other words, CA can enhance problem-solving and critical thinking skills. This is the cognitive aspect of the apprenticeship (Dennen & Burner, 2008).

Many schools, programs, and even courses emphasize critical thinking in the learning objectives. But how does one actually teach such an experiential and complex skill as critical thinking? Most faculty expect students to pick it up along the way as they complete assignments, projects, and exams. After all, thinking is something you do, not something you know. However, experience shows us that expecting students to just "get it" is not always successful. Furthermore, such expectations may be biased against people that think differently than we do.

CA applies the theories of traditional apprenticeships, such as modeling and coaching, to address these problems (Dennen & Burner, 2008). By showing students how we think, learners can start to pattern their thoughts to follow the processes we use to solve problems. Through scaffolding, we can carefully lay the foundation for success within our students. A series of tasks that comes closer and closer to the "real thing" help instructors teach students how to complete a task as well as gain enough expertise to evaluate their own work. Through student reflection, learners can self-monitor and self-correct their behavior, and eventually, master the skills they are being taught.

Education uses outcome controls extensively when performing a summative assessment (Pham & Taylor, 1999). An outcome control is a formal process or mechanism where an actor is rewarded based on the outcome of the process rather than for following a prescribed method or process (Ouchi, 1979). Process, outcome, or social controls may each demonstrate more success depending on the situation. Because outcome controls are the most easily implemented, instructors must learn to craft the learning environment to ensure that outcome controls (such as grading a deliverable based on its quality or correctness) is appropriate and accurate.

CA may help faculty engage students in two key ways: by increasing student self-efficacy and enabling outcome controls to be more effective in measuring student success. This paper will first explore these themes, then share a small example of using CA in a Systems Analysis and Design course, and finally discuss the results from a pilot test of a reorganized assignment.

2. THEORETICAL BACKGROUND

CA is a term that may be unfamiliar to most readers; as such, the prior work is explored in this section. The ability for CA to help students through increasing student self-efficacy is described. Finally, a discussion on how CA can enable faculty to use outcome controls more effectively is presented.

Cognitive Apprenticeship

CA is an extension of traditional trade apprenticeships (Collins et al., 1988; Dennen & Burner, 2008). Instead of lecturers explicating knowledge for students to internalize, CA encourages teachers to model activities, coach students to help them do similar activities, and then fade into the background as students grow more independent. This helps students observe, be coached, and then practice (Collins et al., 1988), with the goal of helping students grow in their abilities. Observing an expert allows learners to create a knowledge schema to store what they are about to learn. Coaching helps them start to build expertise with the close guidance of the instructor. Practice allows the students to then build a memory of how to be successful. Encouraging students to reflect on their own process and how it differs from that of experts is crucial to helping students be able to self-monitor and self-correct (Järvelä, 1995).

Modeling and scaffolding are important concepts of CA. Modeling is a demonstration of the activity by the instructor, performed in such a way that students can reproduce the instructor's actions. Scaffolding is the idea that instructors can use

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additional tools to encourage students to follow a process that will help them be successful. This can range from helpful suggestions to physical support like cards with cues to help students mimic the process of experts (Collins et al., 1988, p. 23). Successful scaffolding and modeling strategies, however, require reciprocal interpretations of the situation by both students and teachers (Järvelä, 1995).

Experts often complete many tasks instantaneously, often without realizing the tacit knowledge embedded within their process. To model problem solving, teachers must learn to externalize their normally-internal processes (Collins et al., 1988, p. 5). This constant explication resembles Mommy-Babble, the string of talking that parents often do to try to help their children acquire language and understanding at a younger age (Sample, 2014). In this model of education, parents maintain a running soliloquy of what they are doing and why. The child will not understand the words, "I am now warming up the bottle in the microwave to bring the formula to a pleasing temperature," but over time will start to recognize parts of it. Given enough time, though, the child will begin to understand the concepts described. Likewise, those that are inexperienced in a particular form of problem-solving need hidden steps in a process to be made visible.

CA has been applied to avionics and medicine (Lajoie, 2009), chemistry (Stewart & Lagowski, 2003), education (Collins et al., 1988), engineering (Dennen & Burner, 2008), instructional technology (Darabi, 2005), and nursing (Taylor & Care, 1999). It has also been adapted to web-based delivery (T.-C. Liu, 2005). It is a robust model to help instructors consider how to make their teaching more student-focused.

CA can help students by increasing their self-efficacy. It can also help instructors use outcome controls more effectively in measuring student learning. While CA is particularly effective with today's generation of millennial learners, the concept is not new and has roots in the communities of practice literature from several decades ago (Lave & Wenger, 1991).

Self-Efficacy

Bandura (1977) posits that self-efficacy predicts behavior. Self-efficacy is the belief that one can perform behaviors that lead to the desired outcome. Self-efficacy predicts behavior because those beliefs determine the effort students will put into something, especially when faced with adversity. This is logical insofar as students that believe they cannot achieve their goals would not persist in working towards that goal; on the other hand, students with self-efficacy have the conviction that they can produce their desired outcomes. Individuals derive their self-efficacy from four primary sources: accomplishments, vicarious experience, verbal persuasion, and physiological states.

According to the Theory of Planned Behavior, most human behavior is goal-driven and is predicted by an attitude towards an action, belief about the social norms, and belief that the action is within the control of the individual (Ajzen, 1985, 1991). But measuring that perceived control can be problematic, as the way individuals form perceptions about control over a situation is not visible (Ajzen, 2002). Ajzen cites Bandura's work on self-efficacy as the most influential on perceived behavioral control and points out that they are defined in almost identical ways in text, but that perceived behavior control includes both self-efficacy and controllability. Interestingly, of the two sub-factors, self-efficacy alone always exerted control. Thus we see that the Theory of Planned Behavior supports the importance of self-efficacy in motivating goal-directed behavior.

CA can improve student self-efficacy. This is achieved by participating in and adapting to change, working through problems, and learning and practicing reasoning skills within the context of the problem (Dunlap, 2005). CA also provides students with a feeling of success early on in the learning process. The modeling provides the framework for knowledge, the coaching provides quick success, and then the practice occurs to solidify the knowledge gains. Without self-efficacy, the practice is less likely to persist when a problem gets difficult.

Process and Outcome Controls

The concept of controls as used in this work is adapted from the business processing outsourcing (BPO) literature. In BPO, the outsourcing party uses policies and rewards to regulate the actions of an outsourcing partner to regulate their behavior (Choudhury & Sabherwal, 2003; Kirsch, 1997) because their goals may only be partially congruent (Ouchi, 1979). Control mechanisms allow the outsourcer to exert control over the actions of the outsourcee (Tiwana & Keil, 2009). This becomes necessary when there is an agency problem: what is good for the outsourcee may not be good for the outsourcer (Eisenhardt, 1985).

These controls can be formal or informal. Formal controls leverage performance evaluation and rewards while informal controls rely on social and people-based relationships to align the goals of the actors (Choudhury & Sabherwal, 2003).

Formal controls can be process or outcome controls. A process control rewards following a process or rules to accomplish the work, which necessitates surveillance into how the work is accomplished (Ouchi, 1979). An outcome control focuses instead on the end product: it rewards sufficient quality and a price fair, like the market determining through competitive bidding how much an item should cost (Ouchi, 1979).

Informal controls can include clan mechanisms, where social structure and relationships influence the actions of others within the group (Ouchi, 1979). This can be difficult in IS development projects because the process of clan controls emerging takes significant time, especially in diverse work teams. Organizations support clan controls by developing social capital (i.e. building relationships) and creating shared values and vision (Chua, Lim, Soh, & Sia, 2012).

In outsourced IT projects, outcome controls are more effective (S. Liu, Wang, & Huang, 2017). But interestingly, the capabilities of the client and vendor both significantly impact the success of outsourced projects.

The most successful relationships have a blend of formal and informal controls because informal control mechanisms can strengthen the influence of formal behavioral control mechanisms (Tiwana, 2010).

In teaching, we use a portfolio of control mechanisms to influence the behavior of students. We use formal process controls such as our course policies found in the syllabus. For instance, we may have an attendance policy that requires students to participate in class. This is not done because we want a large audience; instead, we believe that attending class and participating in the discussions will improve student performance. This belief is based on many semesters of experience – students that we do not recognize during the final exam because we only saw them once or twice rarely do well in the course. Thus, we try to get students to come to class. We can also use completion and participation grades. These reward students for trying. These rewards are granted because we believe that students will learn more by participating and completing an assignment, even if we do not measure the quality of the outcome.

We use formal outcome controls constantly by assigning grades based on the quality of student work. Most exams are a great example of this: we do not measure how long students studied, or how hard they tried, no matter how many students beg for extra points at the end of the semester because of their efforts. The exams, homework, and other summative assessments are outcome controls because rewards are given regardless of what processes students used to achieve those results.

We also leverage informal controls. Students tend to behave in a socially appropriate way because of the social capital students have earned over semesters of interaction and the expectation of future interactions. We can also tap into clan control when we assign group work. The hope is that relationships will keep social loafing to a minimum because of the unwritten rule among students that each person does their part because they will see each other in other classes.

Outcome controls are most effective when the performance risk is low; in other words, the students must have both the ability to complete the task as well as the confidence that they have the ability. In class, this is self-efficacy. If students know how to complete a task and are confident that they can complete that task, then outcome controls are appropriate. When they are not yet there, process controls need to be provided to help students build the capabilities needed to be successful.

Critical Thinking

Critical thinking is defined as "the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action" (Scriven & Paul, 1987). Assignments designed to enhance critical thinking must therefore operate on these dimensions.

To help operationalize this further, the Foundation for Critical Thinking recommend seven Universal Intellectual Standards. They are clarity, which is that an idea has been elaborated fully, accuracy, which is that an idea is verifiably true, precision, which is that an idea is detailed and specific, relevance, which is that ideas are connected to the question at hand, depth, which is that answers address the complexity of the question and context, breadth, that we have considered alternative ways to address a question, and logic, which is determining if a particular solution makes sense ("The National Council for Excellence in Critical Th," n.d.).

Thus, a cognitive apprenticeship approach to teaching that seeks to model critical thinking will challenge students to address all of these dimensions during a learning activity. As students provide ideas, the instructor should ask clarifying questions to determine if ideas could be further elaborated. The instructor would also push back to challenge students on if an idea is true or not, and maybe give counter-examples. Students would be asked to be more precise and give better details. Ideas would be challenged for relevance to the context. Students would be asked to address the complexities of a situation. They would be asked to consider other points of view, possibly by evaluating competing ideas from peers during the lecture. And students would be asked to assert expertise by explaining the logic of a solution.

3. TRYING IT OUT

This paper reports on a redesigned class period. The introduction to logical entity relationship diagrams (ERD) was adapted to use the primary principles of CA. This was done to help students prepare for outcome control mechanisms, i.e. summative assessments. This change occurred in an undergraduate Systems Analysis and Design course.

Creating an ERD is often difficult for students. Students frequently feel overwhelmed at the terminology, symbols, and complexity of the scenarios they are asked to model and the rules associated with modeling data. Because students will be at different levels of knowledge coming into the course, the first several assignments are more formative than summative. For this first in-class assignment, students are graded based on adherence to the key rules, as specified in the assignment page (provided in the Appendix).

Class Flow

Students first complete a 5-question multiple-choice quiz covering assigned ERD readings from the night before. The quizzes prime students to be thinking about the most important aspects of the topic for the day, encourage them to be on time to class, and provide a level of accountability for preparing for class. The instructor peeks at the results to see which questions students struggled with most to help drive the direction of discussions.

After the quiz, the instructor discusses the key aspects of ERDs: the entities, the relationships, and the attributes. This is a 15-minute question-and-answer session. The goal is to orient students to the task as quickly as possible and provide scaffolding to help students avoid common pitfalls.

Following the mini-lecture, the instructor prompts students to provide a context for an information system that would have lots of data required. If students cannot come up with an idea in about a minute, a car dealership is provided as an example for the class. The context is discussed briefly to make sure everyone is on the same page as to the data requirements. In the interest of time, formal requirements are not written up for this assignment.

Students are asked to provide the context so that the topic will be fresh in their mind. They are asked to follow the steps outlined. This enhances critical thinking by letting students set the context by which future ideas will be measured for relevance and accuracy.

Based on the student-provided context, the instructor creates a logical ERD to store the needed data. Care is taken to go slowly enough that students can follow along, and the instructor discusses aloud what is being done and why. The instructor introduces a few common mistakes on purpose while waiting for a student to notice and comment on the issues. If students do not identify the issues, the instructor asks if there are any errors. This is to help students learn that creating an ERD is not easy for experts and to prep them to look for errors in their own work. It also models critical thinking on the accuracy, relevance, precision, and logic dimensions.

The instructor models a four-step process: 1) identify the key entities, 2) determine the relationship between the entities, 3) think of questions we will need to ask our system, and 4) create attributes to hold the data needed to answer those questions. This process was created by the instructor after reflecting on how they did something that was natural to them at that point. And using the model helps to model clarity in critical thinking processes.

After modeling the process, the students are provided the in-class assignment shown on the second page of the appendix and given time to work on the problem. This is a small problem with about five entities. Students are not told at the time, but they earn half credit for turning anything in. Students earn 10 points for naming at least three entities, 10 points for naming all relationships, 10 points for labeling cardinalities, 10 points for creating attributes for the entities,

Table 1. Steps for Cognitive Apprenticeship

1	ERD reading prior to class.
2	A short quiz on the ERD reading.
3	Class discussion/reiteration/clarification of key concepts
4	Students create a context.
5	The instructor creates ERD for the context using the 4-step process.
6	Identify the key entities
7	Determine the relationship between the entities
8	Think of questions we will need to ask our system
9	Create attributes to hold the data needed to answer those questions.
10	Students complete a small in-class assignment.
11	Students pair up and compare.
12	Students graduate to more complex assignment.

and 10 points for providing reasonable queries that would be needed.

During the time students are given (usually about 25 minutes), the instructor prompts them with hints like "Don't forget to identify your entities first. Can anyone remind me what an entity looks like in an ERD?" This scaffolding pairs with the scaffolding provided in the assignment page. It also allows the instructor to model all seven of the critical thinking Universal Intellectual Standards.

The instructor circulates throughout the classroom to provide coaching to students. Since this will be the first logical ERD students create, when any student heads in the wrong direction (such as creating a Data Flow Diagram instead of an ERD – and yes, it happens), quick feedback is given. The instructor follows the mantra of "slow to prompt, quick to correct" to encourage students to use their own recall to complete tasks while preventing incorrect learning.

When there are 7 minutes of remaining class time, the instructor invites students to pair up and provide feedback to their neighbor. Students then provide (hopefully constructive) feedback. Students are encouraged to correct their diagram as they get feedback to make their solution better. Finally, 2 minutes before the end of class, the instructor reminds students of all of the rules for ERDs and asks them to evaluate theirs. Class ends with "Once you have finished your diagram, and have met all of those rules, turn in your diagram."

Students are then assigned a similar business case for their next logical ERD, to be completed before the next class. This is the "fade" portion of CA: students work more or less independently, seeking help during office hours or via email if needed. Table 1 summarizes the steps taken to leverage the CA approach.

4. RESULTS

As seen in the appendix, the objectives of the assignment were not to have students create a better logical ERD than other sections that were taught in a longer lecture format. Instead, the primary objective was to help students become confident in their ability to follow a process. This helps students know where to start, be less afraid of a blank sheet, and increases self-efficacy.

Anecdotally, students completing this assignment were subsequently more successful than in previous semesters. The only students unsure of how to start in the next class were those students that had been absent. The next class is a full day of coaching and fading, using a larger business case that has a solution with about 8-10 entities. I asked the students sitting next to them to share the four-step process with their neighbor in order to tap into peer teaching and provide them with the learning opportunity of explaining a process in their own words to someone else.

It is important to note that the logical ERD grades were not any better on this assignment. Students had been able to grasp the rules equally well regardless of which teaching method was used. Again, improving that first formative assessment was not the objective. However, the exams, which were reused from prior semesters, told a much different story. The average in prior semesters for the ERD exam hovered around 78%. After teaching ERDs using CA, the exam average was 92%.

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The method was appreciated by students. A few students remained after class ended to compliment the instructor on such a great class, and how complicated the book made the diagrams seem, and how easy it is now. Because of the positive feedback, additional classes were adapted to fit the model-coach-fade paradigm of CA.

Of course, this method of teaching may seem like just another active learning technique. This is true: active learning works in part because CA helps students improve their self-efficacy. In fact, many active learning techniques will work within a CA paradigm. But mindfully slowing down to fully explain every step of the process and remembering why it was important to students' development helped this instructor more effectively apply active learning.

5. CONCLUSIONS AND FUTURE RESEARCH

Cognitive apprenticeship is one of many tools available to teachers that can help instill difficult-to-teach attributes in our students. Critical thinking is one such desirable attribute that is often discussed but rarely provided with a methodology to teach. Modeling effective problem solving that address all seven Universal Intellectual Standards of critical thinking can help students build their own skills as a critical thinker through CA.

This paper reports on a single activity in a single class of a single course. It is extremely limited in scope. This was designed as a proof-of-concept, a one-off test to see how it would impact student experiences for a topic that tends to be difficult for students the first time they encounter it. The goal was not to make a generalizable statement of how all teaching and learning should be accomplished; rather, it was to experiment with a new way of thinking about teaching critical thinking and to mindfully model the attributes we wish to develop within our students in light of CA literature.

Future work should explore in a quantifiable way how CA techniques impact self-efficacy, critical thinking, and overall student learning. Such an experiement should control for student and subject differences. Such a project would provide more information on generalizability and fit to different topics and student attributes.

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Appendix: Assignment

Assignment Objectives

1. Help students face their fear of a blank screen and not know how to get started
2. Model students in the 4-step process described in class
    a. Consider entities
    b. Determine Relationships
    c. Determine Question
    d. Model attributes
    e. SO THAT: they can draw a logical ERD
3. Help students remember the mechanics of creating an ERD:
    a. All entities must be named
    b. All entities must have a primary key
    c. All relationships must be uniquely named
    d. All relationships must have a minimum and maximum cardinality on both sides of the relationship
    e. All entities must have attributes
4. Help students avoid common errors:
    a. Blank attributes or those named “Field” (the default in the software used to draw ERDs)
    b. Un-named relationships
    c. Unlabeled minimum cardinalities
    d. Entities that shouldn’t be entities
    e. Missing common entities
    f. Reversed cardinalities
5. Help students gain comfort working in LucidChart and its features
    a. Shading headers and rows
    b. The reverse button for relationships
    c. Moving stuff around to keep lines from crossing
6. Push students to act quickly and fix errors later because this is an iterative process

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Food Drive ERD In-class

BITS has been pressed into service to create an information system to help manage our annual food drive. Since you are in ISTM 320, you are helping to create the data model. Everyone is asked to create their own ERD and members of BITS will vote on the best solution at their next meeting.

The food drive is run by volunteers. Volunteers collect names of donors. Other volunteers contact those donors to ask for food or money. The donations are tracked by the donor who provided it and the volunteer who collected it. Food products have a weight, a type (fruit, vegetable, meat, soup/stew, starch, milk product), and an approximate value.

Some common questions (queries) we will want to answer are:

1. Who is the top donor, by weight of food?
2. Who is the top donor, by value of donations?
3. Who is the top volunteer, by weight of food?
4. Who is the top volunteer, by value of donations?
5. How much food was donated per day?
6. How much food was donated by weight?
7. What is the value of all donations?
8. What day of the week is the most effective day for donations?

1. Entities

What are the major entities you will need? Create those entities with the default 3 fields in a new logical ERD using LucidChart. Don't forget the correct type of entity for a logical ERD!

2. Relationship

Determine how the entities will be related. REMEMBER: this is the relationship of data at rest, NOT processes in how the data are produced. Model those relationships using Crow's Foot Notation on your Logical ERD in LucidChart.

3. Questions

I have given you a list of 8 questions. Are there 2 more you can think of? Add those to your list of questions. Put the new questions as a note on the LucidChart logical ERD.

4. Attributes

What attributes will you need to be able to answer all 10 of your questions (the 8 provided and your 2 additional questions)? Model those attributes in the logical ERD in LucidChart.

Turn it in

Turn in your logical ERD on eCampus. It should have your entities, relationships (remember to label minimum AND maximum cardinality all relationships), and attributes. Don't forget: all relationships must have a unique name.