The Process of Becoming a Physics Expert from the Perspective of University Physics Professors

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Abstract: Results from a qualitative interview study of three physics professors at a large public research university are presented. Faculty view building physics expertise as moving through stages, developing knowledge skills, and adopting the norms of the community, which is consistent with the legitimate peripheral participation model.

Expertise research has provided insightful ideas about how people learn and what educators could do to move students toward greater expertise (National Research Council, 2000). Research on physics expertise, particularly, has shown how physics experts differ from novices in their problem solving skills (Chi, Feltovish, & Glaser, 1981; Reif & Heller, 1982). However, physics expertise research thus far has focused on cognitive aspects of the physics expert rather than on how one becomes an expert. The cognitive view of experts is rooted in a positivist perspective that assumes learning and knowledge happens in the mind (Rogoff, Matusov, & White, 1996). To learn more about the process of becoming an expert and the best conditions to facilitate this process, a constructivist view of learning is needed.

Theoretical Framework

Constructivist theories and perspectives, such as situated cognition, situated learning, distributed cognition, and learning as transformation of participation, place learning within a context (Brown, 1989; Lave & Wegner, 1991; Rogoff, et al., 1996). Within a context suggests that "learning, thinking, and knowing are relations among people engaged in activity in, with, and arising from the socially and culturally structured world" (Lave, 1993, p.67). Learning as situated within a context leads to an exploration of the apprenticeship model of learning as the foundation for the process of becoming a physics expert.

The perspective of learning as transformation of legitimate peripheral participation within a community of practice is an apprenticeship model that describes the trajectory from newcomer, or novice, to old-timer, or expert. The apprentice, or novice, begins the journey as a legitimate peripheral participant, where *legitimacy* is defined as recognition by other community members that the apprentice can be a part of the community. The apprentice is given legitimate access to participate in the community with minimal responsibility (Lave & Wegner, 1991). Over time, the apprentice is acknowledged by the community as having legitimate potential of becoming a full participant in order to increase their *centripetal participation* as an old-timer. Centripetal participation toward full participation describes the increased engagement of a participant within the community of practice.

Within the community of practice, increased participation also implies the replacement of old-timers. Furthermore, the reproduction cycles of communities of practice leave an "historical trace of artifacts; physical, linguistic or symbolic, and of social structures, which constitute and reconstitute the practice over time" (Lave & Wegner, 1991, p. 58). As old-timers retire, they leave a legacy and knowledge that is passed down from one generation of old-timers to the next. In physics, the reproduction cycle is reflected in the basic physics knowledge attained from

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physics courses, the skills acquired from a productive scientist, and the social norms adopted to function as a member of the community (see Figure 1). In this paper, physics expertise is considered a status to be attained through continual transformation of participation within a community of practice. Physics professors at a research university can be categorized as physics experts because they have followed the legitimate peripheral participation model, changing their participation from students, to teachers, mentors, and researchers throughout their careers.

The purpose of this paper is to describe the process of becoming a physics expert from the perspective of university physics professors, which may be constructive for characterizing physics expertise. The research question is: "How do physics professors at a university describe the process of becoming a physics expert?" To investigate this question, a qualitative in-depth interview study of elaborated case studies of three university physics professors was conducted.

Method

This section presents the participants, data collection, data analysis, and validity measures for this qualitative in-depth interview study.

Participants

Participants for this study were White males that received their Ph.D. in physics from research universities across the United States. Leebob and Albert, experimental physicists, and Mathew, a theorist, went through the customary undergraduate, graduate, and post-doctoral sequence in physics before assuming a faculty position at a research university. These three professors were purposely chosen both for the researcher's established rapport with them and for their knowledge on the phenomenon of becoming a physics expert (Patton, 2002).

Data Collection

Data was conducted through individual qualitative in-depth interviews. All participants gave informed consent and agreed to be videotaped. Based on the experiences of the participants as students, teachers, mentors, and researchers, Rubin and Rubin's (2005) description of a tree and branch structure was used for the interviews. Four main research questions were outlined by subsidiary questions that asked about experiences as students, teachers, and mentors. I also inquired about the participants' perspective on expertise in physics. The three interviews were transcribed and proofread prior to an in-depth analysis.

Data Analysis

Data analysis took place in several, often overlapping stages. Since qualitative data collection and analysis is an evolving, ongoing process, and analysis involves organizing and breaking the data into little pieces (Bogdan & Biklen, 2007), many of the resulting themes and concepts originated during data collection and transcription. Following Rubin and Rubin's (2005) concept recognition and elaboration, concepts and themes from the first transcript were categorized. Then, the next transcript was examined for similar themes and synthesized into a coding scheme, followed by another search in the first transcript for instances of similar themes. Finally, the last transcript was analyzed, using the same procedure. Ten to fifteen individual codes from each transcript were synthesized into 5 main themes. From one of the main themes, *process,* the 3 codes emerged and are discussed in the results section of this paper.

Validity Measures

Validity measures include transparency and reflexivity. First, I have had physics courses in previous semesters with two of the participants, Albert and Mathew, and during data collection, I was a student of one of the participants, Leebob. My interactions with Leebob during class time and meetings in his office regarding homework affected my subjectivity. Additionally, I acknowledge that I am the primary research instrument and have adopted the practice of transparency (Ortlipp, 2008). As a current physics graduate student, my own attitudes and beliefs about the process of becoming an expert certainly influenced my interpretation of the data. I took the role of student whenever I interacted with these participants. Second, I practiced "reflexivity, the process of critically reflecting on the self as a researcher" (Merriam, 2002, p. 26) as an internal validity measure. I kept a reflective research journal throughout the research process to keep track of any biases toward the data and any of my choices and experiences that could influence the study.

Results

Results show that the *process*, which directly related to the research question of becoming a physics expert, involved *stages*, *skills* and *norms*.

Stages

Stages are exemplified in Leebob's transcript as he described the journey he envisions his graduate students going through:

> There are stages. There's the greenhorn . . . It's the novice who doesn't actually really know what you're getting into. And you don't really know what you're doing either, and so you need a lot of guidance . . . but they're learning, and they're like sponges, but they take a lot of time . . . And I've got one student in that stage, and there's a stage where they - where they're actually starting to figure things out. And they kind of have an idea what they're supposed to do . . . So you have people in this stage where they don't really know what they know. Someone who is maybe taking their data or maybe a little bit before or maybe a little bit after and then, at some point - like I say during the writing process, during the real - which is really the hardest part is really understanding what it is you have. At that point, you go, "Aha. I know what I've got here. I understand what I've got." And that's when you're a young expert.

Leebob's descriptions of stages for his students are defined by students' progress in their research projects. Progress from apprentice to expert is dependent on what the apprentice learns as his or her journey develops. These stages of knowledge are transformations of participation the apprentice goes through as he or she becomes an expert.

Complementary to Leebob's description of stages, Mathew also commented on the stages he envisions his students going through:

> . . . the first year I know they are not going to contribute. The second year, I expect them to get to the point where they've learned enough so they can contribute, and in the third year, they're developing expertise in that field, actually, so by the time they're finished, they know as much as I do about that specific field because they've contributed to some of it.

Mathew explicitly defines the stages of knowledge as measured by what the student can contribute to the research project. The apprentice gradually engages in tasks and moves toward the center of the community as he or she gains more knowledge and experience.

Skills

Skills are represented in Albert's response to what process he envisioned his students going through as a list of skills the student should acquire:

> I think students should be comfortable working with generic hardware. So they should be happy to turn on high voltage supplies, and they shouldn't be afraid of connecting up detectors . . . They should be comfortable analyzing data from them . . . you should at least be able to have some experience with understanding what you did with that data and how you would, theoretically, just go about doing it in a different laboratory. And you

> should have skills at communicating the results of that from there. You should know what the question was that was posed, and you should be able to provide some sort of an answer even if it's only the work is still in progress, and this is what we need to do still to get the answer.

The skills listed here are very specific to Albert's experimental physics interest. He and his students work very closely with the equipment they use to gather data for their physics research projects. Working together with the expert ensures acquisition of skills from experienced scientists. Mathew points out, "When you are experimentalists, there's something about working until 4:00 in the morning and passing screwdrivers and wrenches to each other that ends up building a slightly closer relationship."

These activities are a form of legitimate access to participation for the apprentice. However, in contrast to Albert's experience with his students, Leebob did not have such a congenial relationship with his mentor, "I learned most not from my advisor. I learned from the senior grad student in the group, the post docs in the group and talking to other faculty members and other students." Leebob makes it clear that not all communities of practices build direct relationships between expert and apprentice. It may be that the acquisition of skills comes from other members of the community where the knowledge skills spread rapidly and effectively. Nevertheless, the expert has provided legitimate access into the practice (Lave & Wegner, 1991).

Norms

Norms, in physics, as in many other fields of academia, are traditional methods of getting a degree and a set of standards that are expected of a student. Albert refers to a few generalized standards that apply in physics as well as across disciplines:

> First of all, they do know pretty much about what's happening in their discipline, and they know this both by knowing what's happening with the theory of what's going on and the experiment . . . They should know what are the competing theories, what research is happening and especially what funded research is happening.

Here, Albert introduces the standard approach to physics research. However, acquiring physics expertise requires that the student learns not only the basic physics of the research project but also the folklore that is associated with the research. Leebob describes this process for his own research:

> I knew not only the basic physics of building wire chambers, but I kind of knew all the little black magic techniques as well, that are based on - there's physics behind them, but there's a little folklore and, oh, oral knowledge that is passed down from person to person on how to make these things work. It would be people like me passing it to people like you [a student] for example. Mentors, friends who know maybe this part of it or that part of it, and you synthesize it all to become an expert.

Leebob indicates that there are many traditions and customs that make a successful community of practice. Norms can be viewed as a set of guidelines the community follows and should be adopted by its new members. Sharing the norms from generation to generation perpetuates the community of practice through time.

Discussion

Becoming a physics expert, as perceived by the physics professors in this study, depends on students adopting the norms of the physics community, acquiring skills, and moving through stages of learning development. Norms as standards of the community are represented as the boundaries of the community in the legitimate peripheral participation model (see Figure 1). Norms as boundaries distinguish one community from the next. For example, the community of physicists has clearly defined standards as voiced by these professors, but a community of teachers may have a completely different classification of norms.

Norms also guide apprentices to participate successfully in the community with "shared repertoire" (Wenger, 1998, p. 82) of a community of practice. Shared repertoires include "routines, words, tools, ways of doing things, stories, gestures, symbols, action, or concepts that the community has produced or adopted in the course of its existence" (p. 82). A repertoire emphasizes the rehearsed aspect and availability of the practice for future generations. The rehearsed aspect is noted in Albert's description of the process of conducting physics research. When Leebob shared his experience as a student learning the folklore of the field, he portrayed the propagation of stories from generation to generation.

Stages are dependent on the level of knowledge and research contributions the student can make to the research community. In Figure 1, stages are represented in the different shaded circles that platform the apprentice toward becoming an expert. Skills acquired by the apprentice outline the centripetal trajectory for becoming a physics expert. Representative of the arrow in Figure 1, knowledge skills propel the apprentice through the stages of knowledge toward the stage of expertise. According to this study, skills can be attained from different sources as exemplified by Leebob's experience of learning the most from fellow graduate students and post-doctoral fellows. The relationship between mentor and apprentice generate opportunities for the apprentice to acquire knowledge skills from the mentor, but not all skills necessarily come from the mentor. This example augments the understanding that expertise resides not in the expert but in the community of practice of which the expert is only a part (Lave & Wegner, 1991). Since expertise is a status, the apprentice can view any member of the community as an expert.

Conclusion

Becoming a physics expert is a process. From the perspective of three physics professors at a large public research university, becoming a physics expert requires moving centripetally through stages of knowledge toward full participation, acquiring skills from the expert members of the community, and adopting the norms or repertoire of the community. However, before adopting the norms or acquiring the skills, the apprentice must be provided with legitimate access to participation in the activities of the community. Gaining access to the community is the crucial first step to physics expertise.

Recommendations for further research include examining the perspectives of students going through the process of becoming a physics expert, investigating interactions of the community as a whole, and exploring how the members interact with each other. Data suggest that the process of becoming a physics expert is a constant transformation of participation within the community of practice. Yet, how a newcomer changes his or her understanding as he or she goes through the stages and what the conditions are for the transition to expertise still need to be explored.

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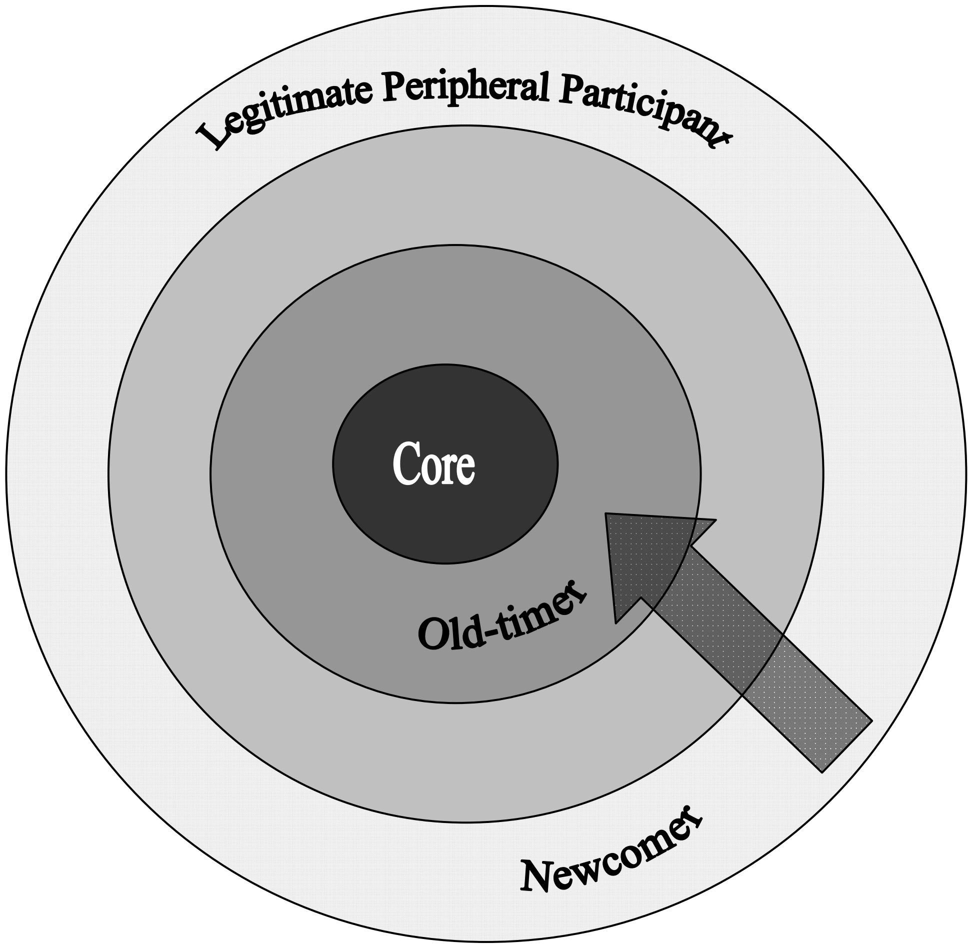

Figure 1. Pictorial representation of a community of practice indicating the location of the newcomer and the old-timer. Line represents a trajectory of the newcomer to old-timer.