Constructing a Model of Physics Expertise

Idaykis Rodriguez[*], Eric Brewe[+*] and Laird Kramer[*]

Florida International University
Department of Physics[*] and Department of Teaching and Learning[+]
Miami, FL 33199

Abstract. Research on physics expertise has predominantly focused on cognitive differences between physics experts and novices where the novices are high school or introductory college students and the experts are university physics professors or graduate doctoral students. Most physics expertise studies declare the experts to be the physics faculty without justifying this decision. To establish more clearly the characteristics of physics experts, we conducted a qualitative interview pilot study of three university physics professors. The professors each had an hour-long interview where they were asked about their experiences of becoming a physics expert. We present the analysis of the question, 'What makes a physics expert?' Analysis of the data resulted in the construction of a model of physics expertise, which indicates that a physics expert is a *specific physics expert* first, acquires *general physics expert* characteristics and then becomes an *expert in physics* or a *boundary crosser*.

Keywords: Physics expertise
PACS:

INTRODUCTION

Expertise research has provided insights about characteristics of experts in many domains and has projected these findings to speculate about how people learn and what educators could do to move students toward greater expertise [1]. Research on physics expertise, particularly, has shown how physics experts differ from novices in their problem solving skills, pictorial representation, problem categorization, and metacognitive skills [2-5]. However, physics expertise research thus far has focused on cognitive differences between novices and experts where the experts are typically university physics professors, or graduate doctoral students and the novices are typically high school students or introductory physics students in college [5-7]. It is common in these studies to declare physics faculty to be the experts without justifying the rationale for considering them experts. While the literature is very descriptive of expert-novice cognitive aspects, it is not sufficient to describe the nature of physics experts; who they are, how they become an expert.

To understand more about the nature of physics experts we will build upon cognitivist and individual learning perspectives by integrating more participationist views on learning [8-9]. We propose using situated cognition as portrayed by Lave and Wenger's [10] and Wenger's [11] model of *communities of practice* to frame our understanding of the nature of physics experts. A community of practice in its simplest definition is a group of people engaged in a shared practice that 'binds' the community together. Physics as a community of practice is a very complex community consisting of many interrelated communities [9]. For example, the nuclear physics community exists within the larger physics community and shares features with the elementary particle physics community.

In conjunction with the model of communities of practice, Lave and Wenger [10] introduce the idea of *legitimate peripheral participation*, which describes how a newcomer develops his or her expertise through transformation of participation in the community of practice. We argue that university physics professors have transformed their participation in the physics community from students to teachers, mentors and researchers. This trajectory is one of developing expertise and thus, these professors have much to offer about their interpretation of the nature of physics expertise. Our purpose is to describe university physics professors' perceptions of what makes a physics expert. To investigate, we conducted a qualitative in-depth interview pilot study of three university physics professors.

METHOD AND PARTICIPANTS

Participants for this study were White males, full physics professors that received their Ph.D. in physics from research universities across the United States. The three participants have gone through the customary undergraduate, graduate, and post-doctoral sequence in physics before assuming a faculty position at a research university. Leebob and Albert are experimental physicists, and Mathew is a theorist.. These three professors were purposely chosen for the researcher's established rapport with them and for their perspective on developing physics expertise [12].

Data were gathered through one-hour individual qualitative in-depth interviews. All participants gave informed consent and agreed to be videotaped. The participants were interviewed not only about their perceptions of physics experts but also about the process of becoming a physics expert. The interview guide had four main questions (see Table 1) followed by subsidiary questions. The three interviews were transcribed and proofread prior to an in-depth analysis. The analysis and results to follow are focused on data gathered from the second main question of the interview guide.

TABLE 1. Main questions used as an interview guide for all three physics professors.

Main Questions
1. Since I am now in the process of becoming a physicist, I can tell it takes a lot of work. Can you tell me about how you came to be a physicist?
2. What makes an expert physicist?
3. Considering the journey that got you to this point, what does a typical day look like for you?
4. Can you describe any defining moments in your physics career?

As a current physics graduate student, the first author's own attitudes and beliefs about being and becoming an expert certainly influenced the interpretation of the data. The first author practiced "reflexivity, the process of critically reflecting on the self as a researcher" [13] as an internal validity measure. A reflective research journal was kept throughout the research process to keep track of any biases toward the data and any choices and experiences that could influence the study.

ANALYSIS AND RESULTS

The responses to the main question of what makes a physics expert were analyzed for emergent themes. A total of eighteen themes emerged from the responses that were synthesized to three main themes. The three main themes construct a model of physics expertise. The model of physics expertise consists of being a *specific physics expert* that helps achieve *general physics expert* characteristics to finally being an *expert in physics.*

The model of physics expertise starts with becoming a *specific physics expert*. This specificity can be seen in Albert's description of physics experts: "When we think of experts, we think of people who have taken a narrow specialty and learned all there is to learn about that narrow specialty." The narrow specialty refers to specific subfields in physics like nuclear or particle physics and within the specific subfields there are particular expertise. Leebob explains, "Well at one time, so I was a hardware guru. I was an expert. Alright? In what? In building wire chambers. Okay? That's really—a wire chamber expert." Leebob's particular expertise lies within the specific subfield of nuclear physics but specializes in wire chambers.

Expertise specificity can also been seen from particular physics projects. For example, when Albert was asked if he considered himself an expert he answered, "Yes I do. In nuclear and particle physics. But more specifically I would say particularly electro production of strange quarks." Knowing all there is to know about the narrow specialty is foremost to being a physics expert because according to Mathew, "Being an expert physicist means by definition that you're an expert in one [sub]field of physics."

Though the participants consider themselves *specific physics experts* they also acknowledge that there are still a few generalized characteristics that apply across disciplines. As Albert explains,

> *First of all, they do know pretty much what's happening in their discipline… they know this by knowing what's happening with the theory of what's going on then and the experiment. [Also] what research is happening and especially what funded research is happening… So I'd say that the people who are experts they're experts because they can apply this type of thing to their specialty.*

These general characteristics presented by Albert refer to what a physicist does in general. If you are an experimentalist, you must understand the theory that can fit the experimental data and if you are a theorist, you must understand the experiments to create theories for them. Knowing the relationship between theories and experiments is a characteristic of *general physics experts* because only then will one be able to do and be funded to do research.

Another *general physics expert* characteristics, Mathew points out, is the ability to ask the right question,

> *You've got to put in the effort to learn the basic physics first in the coursework. You should enjoy the process of doing the physics, not forgetting that you're aiming to answer a question… You also need to learn how to pick a good question to focus on. Find something you're interested in and then learn everything you can about it that other people have discovered, and that'll allow you to pick a good question.*

Commonly experts are thought of as people that can answer questions and solve problems, but the participants of this study are not only claiming that experts answer questions, but also that they need to able to pose a good question.

Beyond acquiring the characteristics of a *general physics expert,* an established expert can institute expertise in other fields of physics. All of the participants in the study asserted physics expertise to be very specific at first, but most of them also asserted that one could carry their expertise into other areas in the field and become experts in that specific area. The ability to cross over into other specialized areas distinguish *specific physics expert* within a *general physics expert* community from *expert in physics*.

Recall that Leebob was a hardware guru in building wire chambers but when we asked if he considered himself an expert he said he had not built wire chambers in fourteen years. We asked him what he was an expert at now and he replied, "I am one of the few people doing kaon electric production," which he claims is his current area of expertise.

As an *expert in physics* one can transition from a very specific physics expertise to another expertise within the same physics subfield like Leebob who went from building wire chambers to kaon electric production, both areas within the subfield of nuclear physics. On the other hand, Mathew points out that an *expert in physics* can transition into completely different fields also. When the spaceship Challenger exploded, Mathew explains the government created a panel of experts to investigate the situation.

> *They wanted a panel of experts including some people who had direct expertise in this kind of rocketry-type equipment. But they also brought in an expert in physics, knowing that they needed somebody with the type of expertise that a physicist could have, who knows all the things that a physicist knows, and though they may not have expertise in rockets, they'll learn it.*

In this situation the *expert in physics* transferred his physics expertise into a field of rocketry, which is a field that applies physics. Mathew adds that a physicist was very beneficial to such a panel of experts because "they could learn what the engineer already knows, but the physicist could learn it quite quickly and then take the basic knowledge that the field of physics gives you, which can be applied to anything."

The model of a physics expert drawn from these three qualitative interviews starts with acquiring expertise in a very specific area of physics to become a *specific physics expert* and as one is developing that specific expertise, they attain certain general characteristics that apply across disciplines. As the *general physics expert* characteristics are developed, one can transition to be an *expert in physics*.

DISCUSSION

The model constructed of a physics expert has transitory stages. The first stage of physics expertise is to be a *specific physics expert* where your research projects or the subfield within physics at large define the specificity. Taking the perspective of physics as a community of practice, it is understandable that specific subfields like nuclear or high energy physics are individual communities of practice that are interrelated within the encompassing physics community of practice. Even within the smaller subfield communities, smaller groups of people create their own communities of practice defined by the projects they are working on. For example, Leebob was not only part of a nuclear group but also the group of researchers studying electro production of kaons.

Since the subfields of physics are nested within the larger physics community, it is through the development of *specific physics expertise* that one attains *general physics expert* characteristics. Wenger's [11] framework defines practice to have five main components, one of them being community. Community has three dimensions: mutual engagement, joint enterprise, and shared repertoire. Mutual engagement is the action of people working together; joint enterprise in this case is the physics that pulls them to work together; and the shared repertoire is the source of community coherence. The shared repertoire is the development of resources and norms that reflect the community's character and further engagement. The general physics community interconnects all the specific subfields of physics through their shared repertoire or the *general physics expert* characteristics. Characteristics that are common to all physicists like asking good research questions and understanding the connections between theories and experiments are elements of the shared repertoire of the larger physics community.

Attaining *general physics expert* characteristics through the development of *specific physics expertise* is then necessary to being an *expert in physics*. Within the communities of practice framework [11], another component of practice is boundaries. Boundaries can define what belongs to the community but also what does not belong and particularly how communities are related to one another [9]. A *boundary crosser* is one that can take elements and concepts from one community of practice into another; an *expert in physics* is a *boundary crosser*.

As mentioned earlier, a community of practice can be defined by the specificity of the project, subfield, or physics community at large. Leebob, for example, crossed the boundaries of the subfield of nuclear physics in working with wire chambers to working with electro production of kaons. Boundary crossing also extrapolates to crossings between subfields of physics because one attains *general physics expert* characteristics that are common within the general physics community. However, boundary crossing does not only occur within the general physics community but also outside the physics community to other general communities of practice such as engineering. Having an *expert in physics* on a panel to investigate why the spaceship Challenger exploded demonstrates the applicability of general physics characteristics to another community of practice. An *expert in physics* can take what they know and span across boundaries.

CONCLUSION

Physics expertise models have thus far been developed from experimental cognitive studies of the difference between experts and novices. The model of physics expertise presented here builds upon the cognitive models and includes authentic input from physics experts about the characteristics of physics expertise. In contrast to cognitive models of physics expertise, which rely on controlled and limited laboratory experiments, the model of physics expertise constructed from interviews with three university physics professors is developed from within the community of physics experts.

As seen from the perspective of the physics experts themselves, physics expertise is much more than one's ability to solve physics problems. Within the communities of practice framework, physics expertise is developed through transforming participation within a community of practice and expanding to other communities. It is through this theoretical lens that we will also view novices developing physics expertise within a community of practice. Such a study will give us further understanding of how to guide physics education at the doctoral level.

ACKNOWLEDGEMENTS

We would like to thank the FIU PER group for their support and professor Linda Bliss for her knowledge of qualitative methods. We'd also like to thank the participants for their valuable insights. This study is supported by NSF Award #0808214

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