Commentary by D. Hestenes:

What do graduate oral exams tell us?

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Administering graduate oral exams is among the more disagreeable duties of the physics faculty at a university. The examining committee is frequently dismayed by the substandard performance of students with outstanding academic records or demonstrated ability for research. Indeed, most exam performances are deemed substandard! Repeating the exam, however, seems unlikely to produce a more satisfactory result or benefit the student, so students are seldom failed. This leaves exam committees with the uncomfortable task of finding excuses to justify this breach of their professional standards.

I raised this problem recently with a colleague heavily involved in updating and upgrading our undergraduate physics curriculum. His response was a diatribe on how the quality of students and the rigors of the exams have declined in the decades since we were students. I can't deny having entertained the same thought myself or hearing it lamented many times before by others. But is it true or merely self-serving? The very next week I came across the following remarks in a perceptive essay by W. F. G. Swann in 1950:[1]

> "Much can be said about oral examinations for doctor's degrees, and in my judgment not much can be said that is good. I have sat in innumerable examinations for Ph.D. at very many different universities, sometimes as a member of the permanent faculty and sometimes as a visitor. In almost every case the knowledge exhibited was such that if it represented the true state of mind of the student, he never should have passed. However, after the examination is concluded there is usually a discussion to the effect that: "Well, So-and-so got tied up pretty badly, but I happen to know that he is a very good man," etc., etc., and so finally he is passed."

Dismal performance on the oral exam is thus a problem of long-standing. Some physics departments have responded by eliminating the exam altogether or by replacing it with some sort of oral report. This is not unlike eliminating word problems from algebra tests or qualitative questions from physics tests because students have so much trouble with them. It seems not to have occurred to the faculty that *dismal oral exams may be symptoms of a severe deficiency in the entire physics curriculum.* I submit that there is good reason to believe that they are symptomatic of a *general failure to develop student skills in qualitative modeling and analysis.*

From my experience, the most revealing questions on oral exams are qualitative, calling for some kind of physical explanation, like "Sketch the specific heat curve for (some material) and explain its shape." In contrast, exam questions throughout the physics curriculum are predominantly quantitative. Consequently, students concentrate on the computational aspects of problem solving without recognizing the crucial role of qualitative analysis. One of the most decisive conclusions of educational research on introductory physics is that failure in problem solving is primarily due to deficient qualitative analysis in the initial stage. In the absence of evidence to the contrary, we should assume that this applies to more advanced levels as well. In the real world of physics research and application, qualitative reasoning plays a more prominent role. Oral exams suggest that implementations of the standard physics curriculum is not adequately promoting this.

If the curriculum is so ineffective at developing qualitative reasoning, how did professors learn it? For an answer, we should examine how the research and teaching experience of professors differs from the coursework experience of students. Typically, a profound transition occurs as the student plunges into research after completing the graduate exam requirements. In the struggle to define a research problem and in direct give-and-take with experienced researchers, the student develops a natural fluency in the kind of qualitative descriptions and arguments that drive scientific research. The evolution of physical understanding during graduate research is a worthy subject for educational research in the future.

Professors who have become sensitized to the importance of qualitative reasoning or "physical thinking," as it is often called, naturally want to convey it to students. They emphasize it in lectures, demonstrate it in problem solving and exhibit it in physical explanations, sometimes with stunning brilliance. Understandably, they are reluctant to acknowledge the obvious fact (thoroughly documented by educational research) that their efforts have little impact even on the brightest students in introductory physics. Nor do many question the effectiveness of lecturing in advanced courses. Undoubtedly the preparation and delivery of lectures is good training for professors. Should not instruction be designed to give students comparable practice in devising, articulating and evaluating physical arguments?

Oral exam results provide just one among many clues that the standard physics curriculum is not all that its cracked up to be. To do better physics departments will have to get serious about promoting instructional experimentation and innovation.

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1. W. F. G. Swann, The Teaching of Physics, *Am. J. Phys.* **19**, 182-187 (1950).

W. F. G. Swann on teaching physics

Am. J. Phys. (1950)

• There "is no teaching physics, there is only inspiration to learn. . . . The teacher may stimulate the student to reach this goal, but the journey to that goal must be made by the student himself."

• "In seeking to understand new ideas, the student must, in a sense, travel the same path as the originator of the ideas. To do this, however, he does not have to be a Newton or an Einstein, for he has beside him his teacher to steer him away from unfruitful paths and illuminate the beauties of the true path as he develops eyes to see it.

• "One of the most potent influences tending to the development of mediocrity of thought is to be found in the necessity of testing the progress of the student as he learns, . . ."

• "Students believe that parrot-like memorization of facts is the only way to pass exams."

• A student "passes his tests frequently [including graduate comprehensive exams], alas, with very little comprehension of what he has been doing."