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An Explanatory Framework Detailing the Process and Product of High-Quality Secondary Science Practice

Experienced science teachers were compared to Presidential Awardee science teachers in an attempt to explain the process by which high-quality secondary science teaching practice develops.

Best practice research in secondary science education begins with a noble goal: learn from the excellence of past instruction in order to help mold future instructional practice. On the surface, it seems that all we need to do is find excellent science teachers, find out what they do in the classroom, and recreate this in other classes around the globe. Such a simplistic view of educational practice typically fails because individual differences have been neglected. Seeking to recreate the product that someone else has developed is analogous to teaching to the test—you know the desired product; now just get students to achieve the same product. A less myopic, more robust, vision clarifies the conditions by which best practice succeeds. If transformations in teaching practice are achieved by mimicking best practice performances, every participant who attends a National Science Teachers Association (NSTA) conference would be transformed each time they see an exemplary practitioner's presentation—the research tells us otherwise. Specifically, professional development experiences need to be personalized and sustained to create significant, lasting classroom improvements (National Board for Professional Teaching Standards, NBPTS, 2000; Supovitz & Turner, 2000). Short professional development experiences can be motivational in the short term but lack sufficient time to be internalized into the curriculum.

If all students are truly going to achieve, then strong leadership and guidance must be established through training and then maintaining high-quality teachers.

Tens of billions of dollars are spent each year on improving teacher quality (American Institute of Physics, 2004; National Commission on Teaching and America's Future, 1996), yet the goal of providing high-quality instruction in each classroom is far from being reached. In fact, test scores are not gaining at a rate that will satisfy either the goal of Science for All Americans—Project 2061 (AAAS, 1993), or the tenets of No Child Left Behind, NCLB, (U.S.DOE, 2002). So what is working? What is not working? What can be shared globally?

In 2000, the U.S. Department of Education (DOE) (Program and Policy Studies Service, 2003) reported that highly qualified teachers staff only 55% of the science classes in the U.S. NCLB legislation requires three criteria to be satisfied before a teacher is considered highly qualified: complete a bachelor's degree, possess a state teacher certification, and major in the field taught. Approximately 30% of America's students are being left behind in the current system (Schmidt, 2005). Left behind means that students are not competent in all or the majority of the basic skills and concepts as they matriculate through the grades. One can attempt to debate the merits of each essential skill or concept being assessed, but assessments such as TIMSS clearly illustrate again and again that a large portion of our students are not proficient in mathematics and science (Schmidt, McNight, & Raizen, 2002). Some argue that the test itself is responsible for the huge achievement gap between those succeeding and those failing, but just changing to alternative forms of assessment does not erase the fact that basic competencies are being missed by far too many. The Nation's Report Card (NAEP, 2002) states that only 53% of 12th grade students have attained partial or better mastery in science, and only 18% of 12th grade students can be considered proficient or better. The challenge is clear. If all students are truly going to achieve, then strong leadership and guidance must be established through training and then maintaining high-quality teachers.

Just as our students need learner-centered environments, teachers need to be engaged participants in professional learning experiences that personally connect to their own teaching setting.

Beyond highly qualified, exemplary science teachers generally are more enthusiastic, involve students regularly in inquiry experiences, encourage students to apply material, are more flexible, and encourage curiosity through questioning techniques (NBPTS, 2000; Penick, Yager, & Bonnstetter, 1986). Exemplary teachers are typically seen as more challenging (Tobin & Fraser, 1989) and excel at transforming their own personal content knowledge into usable pedagogical content knowledge that makes learning accessible to their students (Shulman, 1986, 1987; Yager et al., 1990).

The *National Science Education Standards, NSES*, (NRC, 1996) outline professional development training for science practitioners. These recommendations provide a mix of pre-service and in-service training experiences that teachers should be exposed to. Recommendations include the need for sustained and contextual professional development experiences that require participation and in-depth reflection by the teacher (NBPTS, 1994; Supovitz & Turner, 2000). Further, the *NSES* report the need for science teachers to engage in learning experiences that use process skills such as actively investigating phenomena and interpreting results.

As best practices are united with professional development training for secondary science teaching, two possible avenues can be pursued: a) systemic recommendations and b) assisting the development of individual best practices. America's Choice School Design represents an example of a systemic change initiative (NCEE, 2002); whereas, programs such as NBPTS (1994) look at how to improve individual practice based on the contextual experience that a practitioner currently possesses. The latter issue of assisting in the development of, rather than prescribing, individual best practices is the focus of this study.

Kennedy (1998) found that focusing training on subject matter knowledge and student learning had more impact than focusing on teaching behaviors. The NRC (2000) suggests that professional development should be structured in ways that allow teachers to experience success by creating learning environments that are solid in four areas: learner-centered, knowledge-centered, assessment-centered, and community-centered. Just as our students need learner-centered environments, teachers need to be engaged participants in professional learning experiences that personally connect to their own teaching setting (Zigarmi, Betz, & Jennings, 1977). Further, professional training experiences should be intensive and sustained (Hawley & Valli, 1999; Smylie, Bilcer, Greenberg, & Harris, 1998; Supovitz & Turner, 2000) and should be based on concrete tasks related to student learning (Darling-Hammond & McLaughlin, 1995).

Beyond strong content knowledge, high-quality secondary science teachers engage students in the process of inquiry—not just provide instruction (NCMST, 2000; NRC, 1996). The process associated with how high-quality instructional practice develops is central to this study. By understanding how individual practice develops in effective and ineffective ways, we can better lead individual teachers in the improvement of their own teaching practices. Specifically, what are the foundational aspects associated with professional teacher training (pre-service and in-service) that help to facilitate the development of high-quality secondary science instructional practice?

Method

A mixed methods design is used to study the process and product associated with high-quality secondary science instruction. Two distinct, yet related, tiers provide the foundation of the study—tier one, a quantitative comparative analysis of pre-existing national survey data (Weiss et al., 2001), and tier two, a qualitative collective case study focusing on interviews and classroom observations.

A mixed methods design was selected based on two premises: a) stronger inferences are generated versus quantitative only or qualitative only approaches, at least for the research questions studied, and b) the desired pragmatic ontology is central to mixed methods approaches (Creswell, 2003; Greene & Caracelli, 1997; Tashakkori & Teddlie, 1998, 2003). Stronger inferences can be achieved because of a triangulation and complementarily typology that constantly draws from both tiers: tier one, emphasizing quantitative data and tier two, emphasizing qualitative data (Creswell, 2003; Jick, 1979; Tashakkori & Teddlie, 1998).

This study most closely aligns with Tashakkori and Teddlie's Type VII, a parallel mixed model study, whereby both quantitative and qualitative aspects are central and simultaneously considered during problem formation, data collection, and data analysis (1998; 2003). Triangulation that encourages a continual dialogue or meshing of the quantitative and qualitative approaches from the two tiers of this study allows for strong inferences to be generated through a rich and powerful data set (Tashakkori & Teddlie, 2003). The heterogeneous unification of the data sets that strive for simultaneous dialogue between data does not require that analysis techniques be identical. However, collection and analysis of data follow respective quantitative or qualitative approaches (e.g., collective case studies).

Tier One Overview

Tier one's comparative analysis involves 943 experienced secondary science teachers (ETs) and 340 exemplary secondary science teachers, all with 10 or more years of teaching experience. Recipients of the Presidential Award for Excellence in Mathematics and Science Teaching[1] (PAs) were selected to represent the exemplary group. The data come from pre-existing survey results collected in 2000 by Horizon Research, Inc. (Weiss et al., 2001). The ET data come from a stratified random sampling of secondary science teachers from across the U.S.—response rate 74%. The PA data come from a similar survey (a few questions regarding the Presidential Award were also asked) that was sent to the entire population of secondary science PAs who are still teaching—response rate of 83%.

Tier one results complement the semi-structured interviews and classroom observations gathered during tier two of the study. Tier one data detail the professional issues related to pre-service and in-service teacher development. The HRI 2000 survey questioned both PAs and ETs about their background preparation, current instructional practices, and professional development experiences. This study furthers the findings generated by the HRI study by detailing how (process emphasis) the classroom practices of PAs developed. Thus, tier one helped identify where significant differences occurred, while tier two expanded[2] upon several of the identified key issues.

Tier Two Overview

A collective case study of four PAs detailing classroom observations and semi-structured interviews comprised tier two, the qualitative aspect. The following criteria were used to make selections for the purposeful sampling of PAs used in tier two: (a) they must have earned the award between 1996 and 2001[3], (b) they must teach or have taught within the Midwest region, and (c) they should be part of a representative group that balances life and physical science teachers. PA recipients, though certainly not the only exemplary science teachers, have undergone a stringent criteria and a series of blind reviews at the state and national level. PA selection criteria require demonstration of subject-matter competence, sustained professional growth, understanding of how students learn, ability to engage students, an experiential and innovative approach to teaching, and professional involvement and leadership.

Creating a coherent descriptive framework of the training process involved in developing high-quality practitioners was a central goal of tier two. The collective case study, tier two, builds upon the tier one survey data that identifies clear differences between the development and subsequent teaching practices of PAs and ETs.

By understanding how individual practice develops in effective and ineffective ways, we can better lead individual teachers in the improvement of their own teaching practices.

The classroom observations were conducted on three different days. All observations and interviews were audio taped and then transcribed for analysis. The classroom observations were primarily used to support or refute claims made by teachers during subsequent interviews. Observations detailed the current state of skills and abilities (product), but interviews sought a deeper understanding of how the current practice developed (process). Waiting until observations had been made before conducting the interviews prevented the questions from guiding instructional practice.

The validity of responses made by the teacher during interviews was compared to his/her actions shown during the classroom observations. Any deviations seen were addressed in future interviews. Teachers were not provided with enough detail prior to the observations to allow them to consciously or unconsciously adjust classroom performance in a way that would bias results.

Data Analysis Techniques

Because this study is comprised of two distinct tiers, one primarily qualitative and the other primarily quantitative, reliability and validity are addressed separately for each tier. The way in which the data were analyzed after collection was quite different in both cases. Despite clear methodological differences in the data collection, the results and analysis of the results allow for a unified set of findings that integrate the broader quantitative findings with the more explanatory, yet related, qualitative findings. The sample size, the quality of analysis, and the connections to existing research, all improve the generalizability of the study. This mixed methods study incorporates the inferences gained from the collective case study with those from the qualitative comparison thus allowing for generalizability that is not possible with grounded theory alone (Gall, Gall, & Borg, 2003; Hutchinson, 1988).

Tier One

Reliability for the tier one survey data was determined using Cronbach's reliability alpha scores. Cronbach's scores ranged from .60-.88 for the portions of the survey used in this study (Weiss et al., 2001). Further, the large sample size, N=1283, (n = 943 for ETs and n = 340 for PAs) and the random stratified selection process both help create a strong validity for tier one. Chi-square (contingency tables) was used to see if and where statistically significant differences existed for survey items (Conover, 1999). Since significance can be misleading in studies with large N, Cramer's V Coefficient (V) was calculated to provide the strength of association.

Tier Two

A collective case study provides a unique opportunity to assist with internal validity issues by integrating otherwise omitted subject details into the analysis. Case studies in solely qualitative research typically seek emergent ideas and qualities (Bogdan & Biklen, 1998; Gall et al., 2003), yet this mixed methods design seeks to extend the knowledge base gained by integrating it with the comparative analysis in tier one. The greatest threats to internal validity are likely to be interpretive validity issues from my own biases. My biases are addressed in several ways. First, member checks as well as audit trails seeking repetitive evidence were used to develop support for claims made (Gall et al., 2003). The audit trail included reviewing transcripts of interviews, notes and tapes from class instruction, handouts provided to students, resumes, and other documents shared by the participants. Most commonly, claims were verified with the tier two PAs, and/or interview responses were compared with observation results.

The qualitative data for the class observations and interviews with the teachers were audio taped and transcribed. Transcriptions along with field notes, class handouts, and any other acquired data, were used during the analysis of the PAs. This final set of comprehensive, collective data was coded based on key areas from tier one that needed more clarity (e.g., professional development involvement), or ideas that were not able to be effectively quantified in the tier one survey (e.g., issues of inquiry in the classroom). Six categories were used to represent the results from this study.

Expected Outcomes

Best practice studies typically describe the product that someone else has achieved while neglecting the process and background that allowed successful practice to develop. Using solely a product approach to understanding teaching is counter to all constructivist approaches that permeate science education literature (AAAS, 1990, 1993, 1998; Gardner, 1983; Kahle & Boone, 2000; Kohn, 1999; NBPTS, 1997; NCMST, 2000; NRC, 1996, 2000). By clarifying the process that leads to the current instructional product, clear recommendations can be developed for how pre-service and in-service teachers are trained.

Results and Analysis

Since the tier one's sample size of 340 PAs differs greatly from the 943 ETs and so easier visual comparison can be made, the percentage of PAs and percentage of ETs that responded affirmatively to each statement or question are shown for all comparative contingency tables.

The results were condensed into six distinct categories: (a) Where the Desire to Teach Began (tier 2 data), (b) Training, Degree(s), and Experience (both tiers), (c) Content Knowledge Training and Preparedness (tier 1 data), (d) Transitions in Teaching Practice (tier 2 data), (e) Professional Development Needs and Experiences (both tiers), and (f) Current Instructional Practices (both tiers). The last section, current instructional practices, provides details regarding methodological issues (including instructional activities and objectives), importance of state and National Standards, and assessments used.

Where the Desire to Teach Began

When the four PA participants from tier two were asked why they choose a career in teaching, no clear pattern was seen. Quotes from two of the tier two PAs emphasize the diversity in career paths.

Amy[4]: *While in college, I decided to follow a path of education. I liked science, so I decided to study biology.*

Barbara: *If you asked mother, she would say that school got out in the second week of June, and by one o'clock in the afternoon of that same day I was playing school … .*

Training, Degree(s) and Experience

Although the path that each tier two PA took to become a teacher was unique, the teaching experience of the four tier two PAs closely align with the tier one results. All four of the tier two PAs have 20+ years of experience. This aligns nicely with the 84% of the tier one PAs who have 20+ years of teaching experience (see Table 1).

Having 10 or more years of teaching experience was a criterion used for PA and ET selection, so the 48% of the original HRI sample of national secondary science teachers and 3% of PAs not meeting this criterion were excluded from the study. Although PAs averaged more years of teaching experience, the extra experience does not seem to be the predominant factor in determining the success of high-quality instructional practice.

In addition to having more years of teaching experience, PAs also held degrees more closely aligned with content being taught than ETs (see Table 2). Additionally, PAs more often have higher degrees than ETs ($p < .001$, V = .229). An assumption that PAs have attained more education simply because they, as a whole, have more years of experience may not be correct. Although a greater percentage of PAs have 20 plus years of experience, 84% of PAs versus 60% of ETs, most of these teachers possess a life license, so there is not a mandate to continue taking classes. It is uncertain from tier one data when most PAs and ETs completed their higher degrees. If higher degrees are typically pursued in the earlier phases of a teaching career, then having 10 or more years of experience is not likely to be what determines whether or not an advanced degree will be earned.

All four PAs in tier two have master's degrees or higher, and all degrees are in specific science content areas or science education. All four tier two PAs possess degrees that align well to their current teaching assignments. For instance, Amy almost exclusively taught courses in biology and genetics during the last five years, and her degrees are in biology education and science education, with a biology emphasis.

The tier two PAs align closely with the general tendencies seen in the larger tier one, HRI national study of PAs, in terms of level of experience, degrees earned, and area of undergraduate majors. The four voices seem to

Table 1: Number of years of teaching experience compared for PAs and ETs**

Years Experience	Secondary science teachers surveyed	
	PA%	ET%
10-14	7	25
15-19	10	15
20+	84	60

Note. χ^2 (2, N = 1283) = 65.23. V (strength of association) = .23.
**p < .001.

Table 2: Undergraduate major and education beyond bachelor's comparisons for PAs and ETs

Undergrad Major	PA%	ET%	χ^2	V
Sci./Sci. Education	87	72	5.55**	0.155
Educ.	8	20	-5.07**	0.142
Other	6	8	-1.20	0.034
Highest Degree	**PA%**	**ET%**	χ^2	**V**
Post BS	90	67	8.20**	.229

**p < .001.

provide a fair representation of the more global PA population. Advanced degrees, majors in content area taught, and greater number of years of teaching experience, are all more prevalent among PAs than ETs.

Content Knowledge Training and Preparedness

Looking at composite scores of coursework taken in each discipline, significant differences ($p < .001$) are seen in both physics ($V = .12$) and chemistry ($V = .09$). Specifically, PAs take more chemistry and physics classes regardless of the discipline they teach (see Table 3). No significant differences ($p > .01$) are evident when studying the composite scores for coursework in earth science, life science, or science courses when collectively viewed as one entity—further supporting the claim that PAs do not always have more content just because of extra years of experience.

Since a stratified random sampling procedure was used, all disciplines are equally represented. Thus, the data is not skewed by the discipline taught, yet the depth of training (see Table 2) and the breadth of training (see Table 3) are greater for PAs when compared to ETs.

Table 4 extends beyond the content training received and compares PAs and ETs feeling of preparedness as a current teacher. Table 4 shows that PAs feel significantly ($p < .001$, V ranging from .12-.19) better prepared to teach all five key sub-topics in physics. When all content sub-topics are combined for all disciplines to create a single composite called "content average," no significant difference is seen. Both the PA and ET groups averaged below 50% for the composite content average. These low scores suggest a low breadth of knowledge in the sciences as a whole for both ETs and PAs. Low breadth of science knowledge further suggests that teachers will have difficulty in integrating content from the various science disciplines into the course or courses that they teach.

Table 3: Comparison of education and science content courses taken for PAs and ETs

Courses Taken	PA%	ET%	χ^2	V
Education Courses				
General methods of teaching	90	96	-4.13**	0.11
Methods of teaching science	91	79	4.96**	0.14
Supervised student teaching	72	63	2.99*	0.08
Composite for each discipline	**PA%**	**ET%**	χ^2	**V**
Chemistry	47	36.7	3.33**	0.09
Earth Science	32.5	28.9	1.24	0.03
Life Science	53.2	51.4	0.57	0.02
Physics	33.3	21.8	4.21**	0.12
Total Science	41.5	34.7	2.23	0.06

Note. Composite scores for each discipline are calculated by determining the average percentage of all topical responses within that discipline. The Total Science Composite is the average of all four science discipline composites not including the education courses.
*p < .01. **p < .001.

PAs feel significantly ($p < .001$, $V = .22$) better prepared to teach science process skills (see Table 4). PAs scored significantly higher on all three questions asking about preparedness to teach science process and inquiry skills. As a composite average, 87% of PAs felt very well-qualified vs. 64% of ETs. If PAs generally are well-qualified to teach various content and skills because of positive self-efficacy, then a consistently higher score should have been seen throughout. However, the content average shown in Table 4 that compares PAs and ETs shows no significant difference, but the process average shows significance ($p < .001$, $V = .22$) as do all physics sub-topics ($p < .001$). Thus, prior training and experience seem to be more likely reasons for this feeling of being well-qualified that PAs show more often than ETs.

Additionally, when PAs content preparedness is compared to ETs to teach in the discipline trained, PAs feel better prepared than ETs in all disciplines, significantly so in chemistry, biology, environmental science, physics, and physical science ($p < .001$, V ranging from .07-.18). When comparing the composite averages of all disciplines, PAs still

Table 4: Comparison of PAs and ETs reporting well-qualified to teach specific science topics

Topic Area	Sub-topic	PA%	ET%	χ^2	V
Ear/Sci	NS				
Biology	Struct./function of human sys.	51	59	-2.55*	0.07
Chemistry	NS				
Physics	Forces/motion	48	34	4.57**	0.13
Physics	Energy	50	33	5.55**	0.15
Physics	Light and sound	42	29	4.39**	0.12
Physics	Electricity and magnetism	37	24	4.61**	0.13
Physics	Modern physics	26	11	6.64**	0.19
Envir.	NS				
Process	Formulating hypotheses, drawing conclusions, making generalizations	89	69	7.24**	0.20
Process	Experimental design	83	57	8.56**	0.24
Process	Describing, graphing, and interpreting data	90	67	8.20**	0.23
Content Average		45.1	41.4	1.18	0.03
Process Average		87.3	64.3	7.97**	0.22

NS = No significance noted for any of key topics in discipline. Note. Only significant topics are shown.
*p < .01. **p < .001.

scored significantly higher ($p < .01$, $V = .09$). Both of these findings indicate that feeling of preparedness is closely linked with content preparedness or training within discipline (see Table 4). When considering feeling of preparedness of PAs and ETs to teach outside their discipline area trained, only chemistry and earth science showed a significant difference ($p < .01$)—PAs feel more prepared. Further, when combining all subject areas into one composite average, no significance is seen when a comparison is made between the confidence that a teacher has to teach outside of his/her own area of training. Since overall science content knowledge is relatively low for both groups, it seems that the confidence of PAs, at least partially, comes from their depth of training.

Several things seem clear from looking at the data from Table 4 with the above data: Pas, as a group, feel better qualified to teach physics, chemistry, and science process skills; both groups seem ill-prepared to teach the key content skills for all secondary science disciplines—thus suggesting a limited breadth of content knowledge for both groups; PAs feel better prepared (85% vs. 77%) to teach the discipline that they are currently assigned to teach; neither group feels extremely well prepared (65% for PAs vs. 61% for ETs) to teach science content beyond the discipline(s) of their current teaching assignment.

Transitions in Teaching Practice

Since their initial pedagogical and content training, all four tier two PAs retrospectively saw an evolution in their teaching practice. Professional development experiences were central to significant changes in classroom instruction. Long-term change producing professional development opportunities included sustained events that often spanned several years. The resulting changes in teaching practice were immediate for some while more gradual for others.

Clara's transition is best understood as a journey along a continuum.

As soon as I got my Bachelor's I started my master's. I thought I needed to understand this better if I was going to teach it. Well, all that did was take me up to higher levels of physics … .

[Initially], I am going to say that I was pretty much a chalk and talk kind of person. I would do derivations of formulas and feel really good when I was finished. I thought I was doing such a wonderful job until one of my students came in one day and said, "You going to throw spaghetti all over the board again today?" And, I said, "What" [with a very puzzled look]? He said, "Well, that is just what it looks like to me. It just looks like you are throwing cooked spaghetti on the board." I thought something is really wrong here, because he was not a dumb kid. So, it just made me start looking at what I was doing a little differently.

Transition in Dorothy's teaching practice was spurred on by an unresolved frustration.

I was perfectly happy teaching, but I was very frustrated. I was very frustrated because I had students who would really, really try very hard and just couldn't do it …. I changed entirely from being a more teacher-centered teacher—sage on the stage—to being a student-centered teacher. What I needed to learn was how to be much less rigid, much more adaptable, much more tuned into what the students are saying, listening to the students, making them talk to you so that you can get some feedback as to how they are viewing what you are saying, and making them do work.

Recently, I realized that this is kind of a thirty-year evolution. When I started teaching as a first-year teacher, I think I did what many first year teachers do…. Then, it began to dawn on me that sometimes these students, who are many times brighter than me, don't exactly see the world the same way that I see it. That is when I began to suspect that something was wrong—that something was missing.

The comments on the transitions experienced during the teaching career reveal unique turning points for each PA, but all four PAs share the fact that key professional development opportunities dramatically impact how they currently teach.

Professional Development Needs and Experiences

ETs express a greater need than PAs for professional development in the areas of how to use technology and inquiry/investigation teaching strategies. Technology is the largest professional development need for both PAs and ETs, but ETs show a greater need 74% vs. 63% ($p < .001$, $V = .11$). Further, 44% of ETs and 30% of PAs ($p < .001$, $V = .13$) see the need for assistance in meeting a primary inquiry teaching objective of the *NSES* (NRC, 1996).

Professional development experiences were central to significant changes in classroom instruction.

A long-term or sustained professional development experience strongly impacted the teaching practice of all four tier two PAs. Details of these professional experiences extend the findings from tier one data. The following descriptions provide detailed accounts of the top two most influential professional development experiences and its impact for two tier two PAs.

The Woodrow Wilson Program in Human Ecology (four weeks) and Research Experience for Master Biology Teachers (two year span) had the greatest impact on Amy's teaching practice. The Woodrow Wilson program had a significant impact on assessment issues in the classroom while the Research Experience helped her develop hands-on/inquiry type skills.

For Clara, modeling workshops (two summers) and Project Insight (two weeks), a program offered by Harvard, provided learning that changed the way that skill/content development was taught in the classroom. Both programs focused on innovative, engaging ways to help students learn physics. All the major experiences by the four PAs involved active participation in the learning experiences as they were trained.

Current Instructional Practice

This study avoids defining what concepts and knowledge base should be taught in each science discipline, yet by investigating and then comparing the broader primary instructional objectives that received heavy emphasis, developing a more global framework for high-quality teaching is possible. Table 5 shows the instructional objectives that receive heavy emphasis within the classrooms of PAs and ETs. Composite scores focused on whether the objective promoted basic content/skills or inquiry/constructivist skills/content. Neutral items were omitted from the composites. The composites show that PAs tend to emphasize inquiry techniques and higher order processing skills more than ETs ($p < .001$ and $V = .142$). Likewise, ETs tend to emphasis lower order processing skills such as preparing for the test more than PAs ($p < .001$ and $V = .124$).

Methodological Issues.

The depth and meaning of learning is guided by the methodology that the teacher selects for a given lesson or unit. The methodology selected and the time appropriated for each of the activities/investigations can dramatically impact a student's level of achievement (Cruickshank, Jenkins, & Metcalf, 2003; Marzano, Pickering, & Pollock, 2001; NBPTS, 2000). Tier one differentiates between what the PAs do differently in terms of instructional activities and how class time is spent (Tables 6 and 7, respectively). The discussion with tier two PAs broadened the methods of instruction used to include the role of inquiry and other methodological approaches.

Table 5: Comparison of Instructional Objectives that Receive Heavy Emphasis

Instructional objectives	PA%	ET%	χ^2	V
Learn basic science concepts†	83	81	0.81	0.02
Learn science process/inquiry skills‡	82	69	4.60**	0.13
Increase students' interest in science‡	63	50	4.12**	0.12
Learn how to communicate ideas in sci. effectively‡	55	40	4.78**	0.13
Prepare for further study in science	48	50	-0.63	0.02
Evaluate arguments based on scientific evidence‡	43	28	5.08**	0.14
Learn relationships between sci., tech., and society	35	29	2.06	0.06
Learn important terms and facts of science†	34	49	-4.77**	0.13
Learn applications of sci. in business and industry	20	17	1.24	0.03
Learn about the history and nature of science	16	12	1.88	0.05
Prepare for standardized tests†	12	21	-3.66**	0.10
Composite of instructional objectives	**PA%**	**ET%**	**χ^2**	**V**
Basic content and/or lower order skills†	43	57	-4.44**	.124
Inquiry/Constructivism and higher order skills‡	58	42	5.07**	.142

Note. †Basic content and/or lower order skills composite include instructional practices that develop knowledge using lower cognitive skill levels such as define, comprehend, and memorize.

‡Inquiry/constructivism and higher order skills composite includes active learning processes that require students to think at higher order cognitive process levels such as analyze, synthesize, and evaluate. $N_{PA} = 340$ and $N_{ET} = 943$.

**p < .001.

Table 6: Instructional Activities Done at Least Weekly

Instructional Activities	PA%	ET%	χ^2	V
Work in groups†	89	81	3.38**	0.09
Hands-on science investigation†	89	73	6.03**	0.17
Record, represent, and/or analyze data†	81	62	6.39**	0.18
Follow specific instructions in an activity or investigation‡	71	77	-2.20	0.06
Listen and take notes during presentation by teacher‡	68	77	3.27**	0.09
Use mathematics as a tool in problem-solving	64	49	4.75**	0.13
Answer textbook or worksheet questions‡	50	66	5.20**	0.14
Watch a science demonstration	49	45	1.27	0.03
Prepare written science reports†	40	26	4.84**	0.13
Use computers as a tool	28	15	5.30**	0.15
Write Reflections†	26	20	2.31	0.06
Design or implement their own investigation†	25	13	5.15**	0.14
Watch audiovisual presentations	22	25	-1.10	0.03
Read (non-textbook) science-related material in class	19	23	-1.53	0.04
Work on extended science investigations or projects†	16	9	3.56**	0.10
Read from a science textbook in class‡	13	32	6.77**	0.19
Make formal presentations to the rest of the class†	10	6	2.47*	0.07
Participate in field work†	9	4	3.52**	0.10
Take field trips	1	3	-2.04	0.06
Composite of Constructivist/Inquiry Activities	45	34	3.60**	0.10

Note. †Indicate constructivist/inquiry activity. ‡Indicate an activity that is counter to constructivist/inquiry learning approaches. No symbol indicates an item that may or may not be considered a constructivist/inquiry activity depending on its context. Both † and ‡ are used to find the composite. Affirmative responses used for the † items, and the negative responses used for the ‡ items. [Constructivist/inquiry activities mean that the students are actively engaged in investigating science beyond just verification activities and/or are actively involved in the process of constructing their own learning.] NPA = 340 and NET = 943.

*p < .01. **p < .001.

Table 7: Average Percentage of Time Spent on Different Types of Activities**

General categories of activities	PAs	ETs	χ^2	V
Hands-on laboratory	38	26	7.67**	0.21
Whole class lecture/discussion	28	33	-3.24**	0.09
Non-laboratory small group work	11	10	0.97	0.03
Non-instructional activities	10	11	-0.97	0.03
Other activities	7	2	2.51	0.07
Individual seatwork—reading, completing worksheets, etc.	6	15	-8.76**	0.24

Note. Composite $\chi 2(5, N = 1283) = 33.07$ and V = 0.16. NPA = 340 and NET = 943.
**p << .001.

Table 8 shows individual instructional activities that are used at least once a week. Additionally, Table 8 shows in a composite overview of constructivist/inquiry activities where PAs scored significantly higher ($p < .001$, $V = .10$). Tier one data does not detail the quality of the constructivist or inquiry teaching approaches used, but it does provide a clear indication of the overall instructional environment created. Table 7 provides a breakdown of the time spent on various categories of activities. Clearly, students in PA classrooms typically spend more time on hands-on laboratory investigations ($p < .001$, $V = .21$) and less time completing individual seatwork such as worksheets ($p < .001$, $V = .24$) than their ET peers. Additionally, ETs more often had students follow specific instructions, read non-text material in class, listen/take notes from the teacher, read the textbook in class, and answer text/worksheet questions. These results further emphasize that PAs demonstrate a greater tendency to use constructivist and inquiry learning approaches in their classes.

Tier two PAs provide further elaboration regarding their views and methodological approaches to teaching inquiry. Effective questioning techniques became central to this discussion. For Amy, inquiry and successful methodologies include the use of guided inquiry and the use of effective questioning techniques. The observations of Amy showed a mix of guided inquiry investigations (e.g., science fair projects and a long term environmental study of a nearby park). In addition, considerable time was used during the class debriefing portion of the lesson to build the framework for the next unit. Both the introductory framework and the debriefing were conducted in a KWL type format that

Table 8: Comparison of Assessment Methods Used at Least Monthly

Assessments	PA%	ET%	χ^2	V
Ask student questions during large group discussions	97	98	-1.91	0.05
Observe students and question as they work in small groups	97	96	1.62	0.05
Observe students and question as they work individually	96	93	3.92**	0.11
Use assessments embedded in class activities to see if students are “getting it”	94	93	1.21	0.03
Review student homework	91	96	-6.05**	0.17
Give test requiring open-ended responses	87	85	1.72	0.05
Grade student work on open-ended and/or laboratory tasks using defined criteria	85	78	5.38**	0.15
Give predominantly short-answer test	59	79	12.90**	0.36
Review student notebooks/journals	57	56	0.60	0.02
Have students present their work to the class	55	44	6.56**	0.18
Pre-assess to determine what students already know	47	48	-0.60	0.02
Have students assess each other	38	30	5.04**	0.14
Have students do long-term projects	34	25	5.89**	0.16
Review student portfolios	31	28	1.96	0.05

Note: Although both groups provided open-ended tests during the month prior to filling out the survey (no significant difference noted [p > .01]), ETs gave a much larger percentage of predominantly short-answer tests ($p < .001$). NPA = 340 and NET = 943.
**p < .001.

looks at what is known, what still needs to be learned/discovered, and what has been learned.

> *Inquiry boils down to this thing that I call problem solving. If you have a question, what steps do you take to solve the question? … I guess through teaching my students, I have come up with techniques to help them recognize pieces of information or an activity that can give them the data that will help them solve their problem. One way to get them to do that is to get them to recognize what their questions are. They don't know how to ask the questions. You give them scenarios and you work in groups or as a class and you practice, practice, practice.*

Dorothy believes strongly in a constructivist teaching approach. Her approach places a heavier responsibility on the student to wrestle through learning, questioning, and discovering. The constructivist approach used by Dorothy is heavily based on helping students formulate good questions in the quest of becoming better communicators and problem solvers.

> *I want them [the students] to have the basic question that they want to answer but not necessarily have the answer to it. Inquiry the way that I understand it, not just a buzzword, is fundamental to being a life-long learner. Students should be encouraged to develop the skills of inquiry. Learn to formulate good questions. Learn to reformulate questions once you have the answer. Be self-motivated and self-initiated in terms of if you want to know the answer to a question—go find it. I frustrate the daylights out of kids because I answer a question with a question until finally they go find it for themselves. If you answer the questions for the students, then it is not going to become the student's property … . A solution to a problem in a book is not your solution, it belongs to the author. If you have another solution that fits all the criteria and generates the correct answer, then that is your solution—don't change it. I don't want to make them change to my way just because it makes sense to them.*

Inquiry is achieved in different ways for each of the tier two PAs, but inquiry becomes successful in the view of PAs when the teacher uses effective questioning techniques to guide the students in their learning/investigations.

The classrooms of both the tier one and tier two PAs are typically inquiry focused with frequent use of questioning techniques directed at helping spur critical thinking and problem solving skills. Specifically, PAs more often had students: recording, representing, and analyzing their data; preparing written science reports; and designing/implementing their own investigations—these closely match the goals of science as inquiry found in *National Science Education Standards, NSES* (NRC, 1996).

Importance of National and State Standards.

As a group, the PAs are more familiar than ETs with the *NSES*, 95% vs. 67% respectively ($p < .001$, $V = .47$). Of those who are familiar with the standards, PAs showed greater agreement with the *NSES* ($p < .001$, $V = .33$) and tended to implement them ($p < .001$, $V = .27$) more than ETs.

The degree that the *NSES* are responsible for shaping the current curriculum of either group is best understood by tier two PAs who all discussed the importance and impact that the National Standards have on their own teaching practice. All four tier two PAs value the state and *NSES* differently, but all support the foundational importance of the *NSES* for their curriculums.

For Amy, standards and proficiencies have been in place for years at her school. Amy infers that the *NSES* are just one part in a larger feedback loop that includes: *NSES*, state standards, departmental standards, and individual instructor practices.

> *You have to look at what the standards are, and then you compare that to what you have in terms of lessons; and if your lessons cover those standards, then you just keep doing what you are supposed to be doing. If there is a standard that you haven't included in your curriculum, then you need to do that.*

For Barbara, the individual, departmental, state and national influences on the curriculum taught are similar to those expressed by Amy, but the process of how the curriculum developed was exactly in reverse order. For Barbara, her curriculum followed the following steps of development: she wrote it, she taught it, she submitted it to the state as a department, and then she helped write the current state biology science standards.

> *I would say that it [the curriculum] has been an evolution based upon activities, needs, interest, ways to approach—it has probably been*

gradual; I cannot pinpoint one year when I turned and did things differently … Standards don't bother me at all … . I can live with it because there is not one thing in there that I don't teach. So it is not a problem for me.

Clara sees the importance of having some sort of National Standards in the area of physics, but as the state standards currently read, she feels that there is an unreasonable demand for both great depth and great breadth in all domains of physics. Too her, it would take more than one year to successfully achieve. She generally agrees with the state standards, but feels that some kind of compromise is needed so breadth is included for all areas and depth is limited to a select number of topics/concepts.

Assessments Used

Effective teaching practice needs to tie instructional objectives with sound assessment strategies that measure student growth. Assessment techniques implemented by tier two PAs varied considerably.

Amy's assessments include projects, essays, concept maps, and quizzes. For Amy, assessment techniques should match the goals and content being studied instead of just relying on previous, traditional methods. For years, Amy swung to the other side of the continuum and avoided all traditional forms of testing. Now, she seeks an authentic match between the assessment, the learner, and/or the needs of the class.

Listed from greatest to least important, tests, homework, labs, quizzes, and projects comprise Barbara's assessment tools. For Barbara, certain assessments are used more than others depending on the content and the time of year depends on if students are working on science fair projects. Barbara went on to discuss what happens when students do not perform to the level expected.

I try to look for the reason why. Did I try to teach too much in too short of time? Was the student absent? How did the student do in class work leading up to the exam? If it is something that I feel is my fault, then I go back and re-teach. I can eliminate a question that may have not been clear; I can scale it; I can do an item analysis; I can look at possible areas of interpretation; but if I think that I really did cover the material in multiple ways where I feel they could succeed if they put forth the effort, then adjustments to grades will not be as likely.

The depth and meaning of learning is guided by the methodology that the teacher selects for a given lesson or unit.

Table 8's comparative overview of the assessments used by tier one PAs and ETs shows that formative assessment techniques that monitor progress of student understanding and knowledge are most common. The largest difference is the type of questions predominantly provided on tests—ETs provide much larger percentage of short answer questions ($p < .001$, $V = .36$). Areas where PAs scored significantly higher ($p < .001$) include: questioning students as they work individually, using defined criteria to grade student work on open-ended and/or laboratory tasks, having students present their work to the class, having students assess each other, and assessing student work on long term projects.

The investigation into the current instructional practices of ETs and PAs included three predominant issues: methodological issues, importance of state and *NSES*, and assessments used. More effective classroom practice develops when engaging professional development experiences unite effective methodological approaches with standards and assessments that can monitor success.

Conclusions and Implications

The training received, the developmental progression, and instructional practices of Presidential Awardees (PAs) are significantly different from experienced teaching peers (ETs) in many respects—both quantitatively and qualitatively.

Regarding training, PAs: (a) attain a stronger foundation in their content knowledge area, (b) possess more background in chemistry and physics regardless of the science content area taught, (c) experience sustained, engaging, and personalized professional development experiences that dramatically transformed their classroom instructional practices, and (d) are trained to effectively lead students in developing science process and inquiry skills. This supports the need of effective teachers to transform their content knowledge into usable pedagogical content knowledge (NRC, 2000; Shulman, 1986, 1987)

Classroom methodologies that develop from the professional training and the professional growth experiences articulated by these PAs include: (a) less focus devoted to basic content and more emphasis on embedding content in inquiry/

constructivist learning approaches, (b) greater emphasis on incorporating science process skills into the learning, (c) less individual seatwork exercises/activities and more collaborative hands-on laboratory experiences, (d) greater focus on standards as the foundational component of the curriculum, and (e) less emphasis on short-answer testing while emphasizing more authentic types of assessment such as lab practicals, class presentations, and long-term projects that incorporate self-assessment as part of the evaluation process. These findings are supported from multiple studies and research groups (Marzano et al., 2001; NRC, 1996, 2000; Stronge, 2002).

Regarding training, the specificity of the degree is more important than the number of degrees. Of importance is the need to have the degree in the content area that one teaches (INTASC, 1992; NBPTS, 1994). PAs feel no better prepared to teach outside their content area (NRC, 2000). Even though PAs may possess greater abilities to lead students from a methodological perspective, they see that content knowledge must precede methodological issues when looking at the success in the classroom. Effective methodological implementation is vital when considering student success, but poor content knowledge will ultimately be expressed in poor student achievement (Darling-Hammond, 1999). Thus, at least one degree should be in the science area taught or in science education. A second degree is desirable to strengthen content knowledge and/or pedagogical abilities.

Depth of training in one's field is vital but this study also points out the need for PAs to attain a solid foundation in chemistry and physics. Chemistry and physics are foundational sciences that are necessary for developing a more comprehensive understanding in other sciences such as biology and earth/space. For instance, a discussion in genetics necessitates understanding chemical processes—if more than a surface level understanding is to be achieved. Additionally, biological concepts such as pH, half-life, photosynthesis, and chemical interactions require knowing at least some fundamentals of physics and chemistry (Lederman, 1998). The current, antiquated sequencing of science teaching, used by most, proceeds from biology to chemistry to physics and dates back to the Committee of Ten in 1894 (DeBoer, 1991). The presence of chemistry and physics content knowledge is vital for building meaningful, relevant learning that extends beyond rote learning. Thus, preparation and presentation order in the sciences, specifically chemistry and physics fundamentals, is critical.

A large difference exists between PAs and ETs reporting being well-qualified to teach science process skills. The training in science process skills that a teacher receives directly impacts his/her subsequent implementation or avoidance of these topics in the curriculum. Without effective training in science process skills, prescriptive forms of learning will replace more constructivist, guided inquiry approaches that engage the minds of students in deeper levels of understanding.

To achieve classrooms where guided inquiry, higher-order skills, and science process skills are foundational to the structure of the class, PAs must experience professional development opportunities where learning is engaging, personalized, contextualized, and inquiry centered. This learning for pre-service and in-service teachers must be sustained to promote long-term changes in practice. Sustained experiences encourage modeling of life-long learning.

PAs see state and National Standards as foundational to their curriculum—not obstacles to overcome. Thus, PAs are not ones who teach to the test; yet they still have great academic success with their students on both standardized tests as well as more analytical analysis.

Effective methodological implementation is vital when considering student success, but poor content knowledge will ultimately be expressed in poor student achievement

Providing excellent instruction in each and every secondary science classroom across the U.S. is a goal that must be pursued with unrelenting vigor—anything less ensures that students will miss learning, growing, and achieving to their capabilities. Two distinct approaches to achieving high-quality instruction include: (a) a systemic program that trains all teachers using the same global and possibly myopic set of objectives, or (b) training that focuses on ways that allow teachers to individually achieve mastery of the identified foundational, essential components for high-quality instructional practice. This second view celebrates the uniqueness that each individual teacher possesses while guiding their development based on identified fundamental components found in the aforementioned PAs. Thus, best practice becomes not something to be duplicated; rather, it becomes a directed journey of intentional training suited to the needs of each person.

In a world where time demands and accountability pressures continue to rise for teachers, it becomes imperative that educational leadership provide a more coherent focus for teachers that still allow for individuality. This study provides a mechanism for how high-quality secondary science teaching can be attained by looking first at the foundational structure of skills, content, and training. This structure does not seek to propose an exclusive approach, but the conclusions hopefully serve to facilitate a meaningful foundational structure that can guide pre-service as well as experienced teachers toward improving their own teaching effectiveness. The outcomes of this study provide a fundamental approach for how teacher-training programs can be structured, and how professional development programs can be developed and implemented. The ultimate instructional product that evolves from this process-focused development of effective practice includes: an inquiry/constructivist focused classroom, a strong training in content area, deep questioning and exploration from students and teacher, respect for student differences, high expectations for all, standards-based curriculum structure, and authentic assessments that match the clear objectives.

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Endnotes

1. PAEMST program began in 1983 during Ronald Regan's presidency.
2. The expanded view mentioned is in agreement with Tashakkori and Teddlie (2003) plausible mixed methods approach that goes from the quantitative to the qualitative as a way to broaden one's understanding.
3. The application process for PAEMST was consistent during these years. Application procedures changed for 2002 applicants.
4. Pseudonyms used for participants.