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SUGGESTIVE PICTURES: THE ROLE OF SPRIN IN BOHMIAN MODEL OF HYDROGEN
Jared R. Stenson and Jean-Francois S. Van Huele 1

THE IMPORTANCE OF EQUITY IN CROSS-CULTURAL RESEARCH
Janel Falk Chin and J.D. Wulfhorst 10

IDAHO ACADEMY OF SCIENCE AWARDS 22

Distinguished Communicator Award 23

Distinguished Scientist Award 25

Information for Contributors and Acknowledgments ....Inside Back Cover

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SUGGESTIVE PICTURES: THE ROLE OF SPIN IN THE BOHMIAN MODEL OF HYDROGEN

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ABSTRACT

We argue for presenting the Bohmian interpretation of quantum mechanics and its accompanying pictures early on in the study of quantum mechanics. We look especially at the role of spin in the Bohmian picture of non relativistic quantum mechanics. We present spin-dependent particle trajectories for stationary states of the hydrogen atom. We raise some questions on spin dynamics and the quantum potential and conclude with thoughts on the pedagogical benefit of being exposed to multiple views of a complex theory.

Keywords: quantum mechanics, Bohm, spin, quantum trajectories, quantum pedagogy.

INTRODUCTION

Since its beginning in the early twentieth century quantum mechanics has provided us with interesting topics to discuss. Early on, much debate was directed at formulating a consistent and useful interpretation of quantum phenomena that could be accepted as standard. Einstein and de Broglie proposed realist interpretations that constantly clashed with the positivist proposals of Bohr, Pauli, and Heisenberg. At the 1927 Solvay conference, while Bohr and Einstein had their famous debates, de Broglie proposed what is recognized as the “pilot wave” interpretation of quantum mechanics. Because of the challenges brought against his ideas by Pauli, de Broglie backed off and even accepted the opposing view. This, along with other successes of the positivists, persuaded physicists to adopt the views of Bohr and his colleagues as the standard interpretation [1]. In explaining this view Heisenberg said

> The very fact that the formalism of quantum mechanics cannot be interpreted as visual description of a phenomenon occurring in space and time shows that quantum mechanics is in no way concerned with the objective determination of space-time [physical] phenomena [2].

Hence the interpretation of the positivists became the accepted manner of speaking, conceptualizing, and proceeding in the relatively new field of quantum

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mechanics. Although much progress was made under this banner, which came to be known as the Copenhagen interpretation because of Bohr's pervasive influence, it didn't provide a satisfying conceptual framework for some physicists.

In 1951 David Bohm wrote a standard quantum mechanical textbook that treated the material with a refreshing depth. If this was an effort to convince himself of the standard view, it failed. Only a year later he published two papers [3] that seemed to revive de Broglie's original view, answering the crushing challenges Pauli brought, and denying the mainstream positivistic approach with an equally plausible realist one. Of this realization John Bell wrote in his book on quantum foundations:

> In 1952 I saw the impossible done…Bohm showed explicitly how parameters could indeed be introduced…with the help of which the indeterministic description could be transformed into a deterministic one [4].

Bohm's proposal remained outside the mainstream but has been the subject of active research more recently [5, 6]. We will show that the research inspired by Bohmian questions can be a great pedagogical tool and can help students in making the transition from classical to quantum mechanics by giving them a more concrete conception of the phenomena.

We will use here the hydrogen atom as a prototype. Of the standard view it is often said that "observations not only *disturb* what is being measured, they *produce* it…We *compel* [the particle] to assume a definite position" [7]. This means that in hydrogen the electron is nowhere until it is measured somewhere. Measurement causes an indeterministic collapse of the wave function to an unpredictable yet definite state. Thus our current models of hydrogen consist only of probability distributions in three-dimensional configuration space.

On the other hand, the Bohmian view allows for the existence of a definite physical state of the electron independent of detection, which allows for the conception of electron trajectories. Measurement is said to alter the physical state in deterministic albeit unpredictable ways. That is, prior to measurement the electron is somewhere in the atom orbiting the nucleus. During the process of measurement disturbances in the potential field alter the independently existent physical characteristics in complex and unpredictable ways. It will be shown here how spin dramatically affects electron trajectories [8].

THE BOHMIAN FORMULATION

A Bohmian approach takes the complex space-time solutions to Schrödinger's wave equation,

$$i\hbar \frac{\partial \psi(\vec{x},t)}{\partial t} = -\frac{\hbar^2}{2m_0}\nabla^2\psi(\vec{x},t) + V(\vec{x})\psi(\vec{x},t)$$

associated with a particle of mass m_0 in the environment of a potential, $V(\vec{x})$, and writes them in a polar representation:

$$\psi(\vec{x},t) = R(\vec{x},t)e^{iS(\vec{x},t)/\hbar}.$$

Separating the real and imaginary parts of the equation yields

$$\frac{\partial S}{\partial t}+\frac{\left(\vec{\nabla}S\right)^2}{2m_0}+V-\frac{\hbar^2}{2m_0}\frac{\nabla^2 R}{R}=0 \text{ and}$$

$$\frac{\partial R^2}{\partial t}+\vec{\nabla}\cdot\left(R^2\frac{\vec{\nabla}S}{m_0}\right)=0 .$$

By taking notice that $\rho \equiv R^2 = \psi^*\psi$ we recognize that the second equation is a continuity equation relating the change of ρ, in our case the probability density in a volume, with its flow through the surface of that volume. The first equation can be taken as the classical Hamilton-Jacobi equation with one extra term. As that term is proportional to $\hbar^2$ (the square of Planck's constant), which is associated with quantum phenomena, it has been called the quantum potential (Q) and vanishes in the classical limit $(\hbar \to 0)$. This also justifies, in part, the identification that Bohm makes of momentum, $\vec{p}_{Bohm} \equiv \vec{\nabla}S$, as the momentum of the particle.

This is Bohm's main point of departure from the standard view for once this momentum is identified, *particle* trajectories can be generated from any wave function. For example, in a hydrogen atom of energy *E* and magnetic quantum number *m*, the general wave function in spherical coordinates (r,θ,φ) is

$$\psi \sim e^{i(m\varphi - E/\hbar)},$$

from which

$$S = m\hbar\varphi - E$$

and

$$\vec{p}_{Bohm} = \vec{\nabla}S = \frac{m\hbar}{r\sin\theta}\hat{\varphi} .$$

Therefore, in any $m=0$ state, Bohm predicts stationary electrons, i.e. charges at rest, while in any state in which $m \neq 0$ there is a uniform circular motion about the *z*-axis. This is in contrast to the stationary orbitals that we are all familiar with from standard atomic textbooks.

AN INTERESTING LIMIT

This unexpected result can be slightly modified if relativistic quantum mechanics is considered. For example, it has been observed [9, 10] that taking the non-relativistic limit of the Dirac probability current with a vector potential $\vec{A}$ gives

$$\vec{j} = \frac{\hbar}{2m_0}\left[\tilde{\phi}\nabla\phi - \left(\nabla\tilde{\phi}\right)\phi\right] - \frac{\rho}{m_0}\vec{A} + \frac{\nabla\times\left(\rho\vec{s}\phi\right)}{m_0} .$$

This is a Pauli current; $\vec{s}$ is a spin vector and $\phi = \tilde{\chi}$ where χ (and ϕ) is a 2-component spinor. The ~ denotes Hermitian conjugation. Using a polar substitution, as we did earlier, with $\vec{A} = 0$ and interpreting $\vec{j} = \rho\vec{v}$ as defining a particle velocity, as in the Bohmian approach, we get

$$\vec{j} = \rho\vec{v} = \frac{\rho\vec{\nabla}S}{m_0} + \frac{\vec{\nabla}\times(\rho\vec{s})}{m_0}$$ or

$$\vec{p} = m_0\vec{v} = \vec{p}_{Bohm} + \vec{p}_{Spin} = \vec{\nabla}S + \vec{\nabla}\log\rho\times\vec{s}\ .$$

Thus, both the current density, $\vec{j}$, and the particle momentum, $\vec{p}$, have a new curl term that depends on the spin. In the current this went unnoticed for so long because the spin current doesn't contribute to the continuity equation: the divergence of a curl is identically zero ($\nabla\cdot(\nabla\times f) = 0$ for all *f*). The extra term in the momentum matters however. Does its neglect in Bohm's original approach imply a violation of energy conservation? Also, does this term affect the motion that he predicted, namely the picture of the stationary electrons in $m = 0$ states of hydrogen?

THE QUANTUM POTENTIAL

The Q term in Bohm's Hamilton-Jacobi-like equation provides an answer. Taking

$$Q = -\frac{\hbar^2}{2m_0}\frac{\nabla^2 R}{R}$$ and $$\vec{s} = \frac{\hbar}{2}\hat{s}$$

we can show that

$$Q = \frac{1}{2m_0}\left\{[\nabla\log\rho\times\vec{s}]^2 + [\nabla\log\rho\cdot\vec{s}]^2 - \frac{\hbar^2}{2}\nabla^2\log\rho\right\},$$

or, equivalently,

$$Q = \frac{\vec{p}_{spin}^{\,2}}{2m_0} + [\nabla\log\rho\cdot\vec{s}]^2 - \frac{\hbar^2}{2}\nabla^2\log\rho\ .$$

We may then interpret the first term as a kinetic energy that depends on both the magnitude and direction of spin. The final two terms are not conspicuously kinetic, so we may interpret them as genuine potential energy terms. It is interesting to notice that both the cross and the dot appear in a similar fashion. If the derivation is taken one step further, the direction of the spin drops out of the energy equation completely. Thus, spin magnitude may affect both the energy and the motion of a particle, but spin direction only affects the motion. This will become apparent in the figures of the next section.

Considering that this result was obtained in the Schrödinger limit of relativistic quantum equations, it seems that spin properties may lay hidden in the Schrödinger equation as some have proposed [9, 11, 12]. This is not generally recognized.

This also gives further insights into the nature of Q as proposed by Bohm. Here we can see promise in investigating the fundamental nature of quantum phenomena as encoded in Q.

RECOVERING THE TRAJECTORIES: HYDROGEN SOLUTIONS

s-states

In all $m = 0$ states only the spin dependent momentum contributes to the motion. As this involves the cross product of the gradient of the density function ρ with the spin vector, the resulting motion is always directed perpendicularly to both quantities. For s-states in hydrogen, then, no matter what the choice of initial conditions or spin direction are, the motion is constrained to the surface of a sphere of radius r_0 in a plane perpendicular to the spin direction (fig. 1).

This simulation was performed with a fixed spin vector. We can, however, generalize to involve a time dependent spin vector (fig. 2). In such cases however, a time dependence is imposed on the spin, such as an oscillation in a plane, for example; there is no feedback of the evolving dynamics on the spin.

p-states

In the $2p_z$ ($m = 0$) states the equations become more complicated and so trajectories do not unfold on a spherical surface in general (fig. 3). Instead, as a set of initial conditions are integrated, it can be seen that the trajectories occur on a cross section of a lobe-like surface with a plane that is perpendicular to the enforced spin direction. This is similar to what we see in the case of s-states. When a set of initial conditions is taken to lie in the spin plane (fig. 4) all trajectories lie in a single plane because they all start in the plane they are constrained to.

Because the lobes are centered on the z-axis and straddle the nodal ($z = 0$) plane they are reminiscent of the p-orbitals. If an initial condition is given that lies very near to one of the nodal points, which for the $2p_z$ state of hydrogen form a plane, the denominator in the velocity expression approaches zero so that the velocity itself becomes extremely large. The particle quickly moves to infinity. The $2p_x$ and $2p_y$ orbitals are also recovered with corresponding symmetries.

OPEN PROBLEMS

As was noted earlier, the dynamics of the spin vector itself is independent of the dynamics of the particle along its trajectory, although the trajectory is not independent of the spin dynamics. Even in the case of an oscillating spin vector, the oscillations are imposed on the system and do not exhibit an orbit-spin coupling. If the models used here are extended to include this coupling, then simulations are likely to gain in precision and become more useful for modeling realistic experiments such as in Stern-Gerlach experiments [13].

Another interesting development of this approach has been to uncover some of the characteristics of Q. These issues deserve to be studied further and related to similar work that has been done by others in the space-time algebra language developed by Hestenes [14].

PEDAGOGICAL CONSIDERATIONS: MORE IS MORE

From the foregoing it is seen that taking a different approach to a standard problem can reveal interesting and novel insights [15]. Different approaches stress different concepts and so, when taken together, round out our conceptualization and understanding of phenomena. The standard theory is particularly powerful at facilitating experimental and theoretical results. This is perhaps because it was developed in the wake of some shocking experimental and theoretical developments that needed quantitative confirmation. On the other hand, the Bohmian view was developed with a different aim in mind and so has other strengths. It was originally constructed in order to facilitate understanding and to offer a concrete picture, not to further calculations. Of the standard view Bohm and Hiley write

> All that is clear about the quantum theory is that it contains an algorithm for computing the probabilities of experimental results. But it gives no physical account of the individual quantum processes [16].

Is this search for deep, consistent, and concrete understanding not what education is about? How often do students beg for a concrete example or everyday picture of the phenomena we teach? How often do they ask for a more abstract approach? In addition to knowing the algorithms for computing probable results of experimental configurations, we want, for us and our students, to understand the phenomena and to have a consistent picture by which to think about them. The Copenhagen view does not give us this nor does it claim to. Other perspectives flesh out our view, aiding our understanding, and accelerating our progress. A single perspective may even be educationally unhealthy.

The Bohmian examples we have presented here illustrate this. We presented a quantum equation that uses classical concepts and classical variables. Since most students have been exposed to similar ideas before, they can rely on familiar solution techniques and an understanding of the nature and construction of the equations. They may readily connect it with other physical concepts, applications, systems, and experiences thus constructing an educational "scaffolding." Once this is done, techniques that have been well explored in classical mechanics or computation courses can be applied in setting up and solving a system of differential equations. Throughout the whole process several of the concepts that characterized the problem (momentum, velocity, position, etc.) retain a closer relationship to their classical counterparts. Thus, being already in place conceptually, these entities can be drawn upon to accelerate and not to further confuse the approach.

This may prove especially true once spin is included in the modified Bohmian approach that we pursued above. It yields trajectories that more closely relate to the orbital interpretation as well as gives a physically possible picture of electron trajectories.

Finally, for those who teach, education is primarily an exercise in communication. Even when descriptive of quantum systems, this communication relies on classical concepts. Heisenberg wrote,

> Any experiment in physics, whether it refers to the phenomena of daily life or to atomic events, is to be described in the terms of classical physics. The concepts of classical physics form the language by which we describe the arrangements of our experiments and state the results. We cannot and should not replace these concepts by any others [17].

Thus, although any approach to quantum mechanics will preserve a large degree of unexpectedness, we should package it in as manageable a language as possible. We should consider this when crafting curriculum for young minds**.** Bell continues his quote above

> But why then had [my teachers] not told me of the "pilot wave"? If only to point out what was wrong with it? …Why is the pilot wave picture ignored in textbooks? Should it not be taught, not as the only way, but as an antidote to the prevailing complacency? To show that vagueness, subjectivity, and indeterminism, are not forced upon us by experimental facts, but by deliberate theoretical choice [4]?

To place these phenomena in a more expressible – or teachable – context was Bohm's aim.

Since the differences are ultimately conceptual and not substantive the combining of approaches such as the standard Copenhagen view supplemented by an extended Bohmian one along with a comparison of their respective strengths will allow for quicker solutions with more intuitive interpretations achieved by a broader range of students earlier in their educational experience. This seems healthy.

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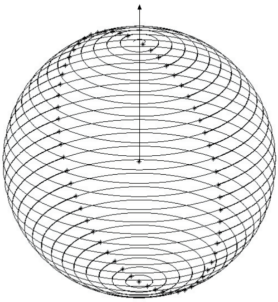

figure 1: Several trajectories in the *1s* state each corresponding to a different initial position. The spin direction is indicated by an arrow.

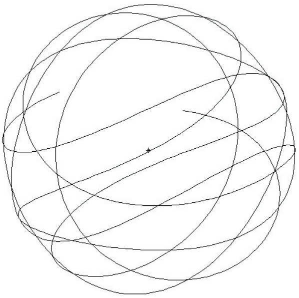

figure 2: A single time dependent trajectory in the *1s* state for a spin that oscillates in a plane.

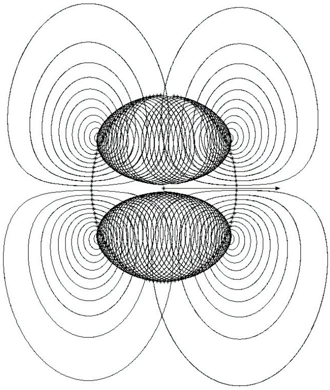

figure 3: Several trajectories in the *2pz* state clearly show the nodal plane. Spin direction is indicated by the arrow.

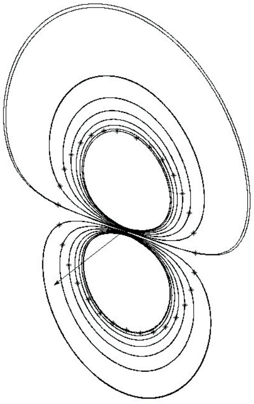

figure 4: Several trajectories in the *2pz* state. All initial positions are in the same plane perpendicular to the spin direction.

THE IMPORTANCE OF EQUITY IN CROSS-CULTURAL RESEARCH

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ABSTRACT

For good reasons, many Indian communities have critically examined, and questioned, the purported benefits of proposals for development and research projects that they did not design in collaboration with others or craft themselves. This article addresses some of the sensitivities that have developed in American Indian communities as the result of cross-cultural methods commonly utilized in social science data collection. Specifically, we analyze the working relationships, interactions, and outcomes of a case study with a Tribe in the western U.S. invited to participate in a regional research project. The project was designed to address a variety of community perspectives; and thus included a phase seeking to analyze the unique historical and contemporary relationship between members of the Tribe and employees at a Department of Energy (DOE) facility that operates a national laboratory within the Tribe's traditional use areas. As is often the case, conflicting management interests have historically strained relations between the Tribe and DOE but despite this political history, DOE, a liaison within our project, mandated their own involvement. While some of the Tribal representatives expressed significant interest in the proposal, a series of discussions over the course of two years illuminated various reasons why the Tribe did not embrace the proposed research project: 1) a frustration with project proposals that consistently fail to include local participants in design phases; 2) lack of Tribal involvement in the data analysis process and 3) use of research protocols that do not engage and empower the Indian participants who may feel disenfranchised by the very system seeking to "help" them via a new project.

Keywords: cross-cultural research, Tribal sovereignty, assimilation, environmental equity, participatory methods

INTRODUCTION

Many American Indian communities blend traditional ways of life with aspects of American culture common among most non-native Americans. Many Indians had little, if any, hand in creating the interface of political systems and institutions through which they experience this blend of native and "non-native" cultural norms and expectations (Bordewich 1996). This article addresses a research project intended as a community development and informational benefit to an American

Indian community.[1] The project's reporting and contractual requirements were not compatible with the timeframes and cultural perspectives of the Tribal Business Council's (TBC). This incompatibility resulted in only minimal interactions with the Tribe on the project illustrating that in research with sovereign entities such as American Indian communities, there needs to be greater sensitivity to cultural practices and increased flexibility in procedures (Thorpe 1997).

BACKGROUND

Setting and Project Orientation

Material presented here derives from a larger research project focusing on public perceptions of operations at a Department of Energy (DOE) nuclear research facility — the Idaho National Laboratory (INL).[2] At the time of the research, the Laboratory maintained several primary missions including energy development (alternative and nuclear), national security, and radioactive waste management. INL's varied missions evolve and thus remain unclear to many who live in the region. Our original research goal sought to identify differences in how regional communities perceived benefits and impacts of INL missions and operations.

The INL has a formal intergovernmental relationship with the Tribe as a sovereign neighbor and key stakeholder in the region. The relationship has included conflict in the past related to decision-making about resource access and uses. Figure 1 illustrates the public's impressions of INL's varied missions as a visual representation of results from a general public survey conducted for the project in southeastern Idaho. The survey indicated that many people in communities surrounding INL perceive storage and management of radioactive waste and environmental cleanup as the primary functions of INL. These findings relate to this case in that the Tribe exists as a key stakeholder with respect to potential impacts related to waste management in the region.

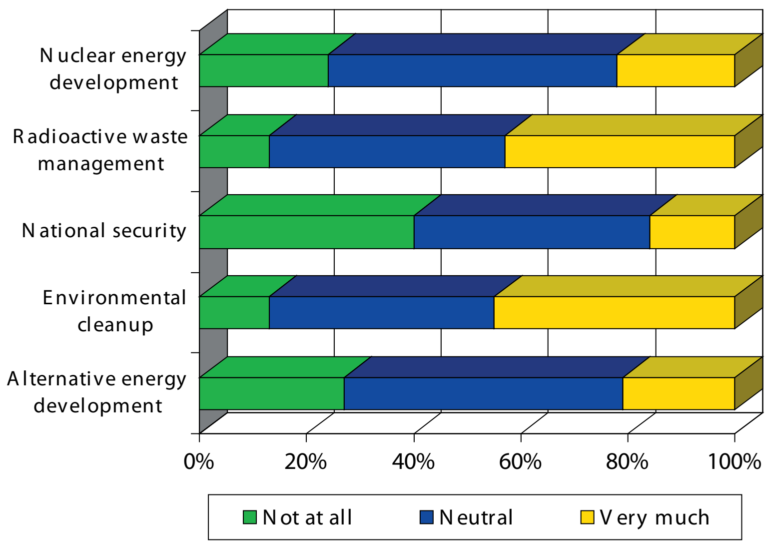

Figure 1. To what degree is each area part of INEEL's mission?

Due to previous on-site subsurface waste disposal, INL operates with significant political attention from a variety of stakeholders including special interest groups and surrounding communities. Much of the attention revolves around prevention of radionuclide and heavy metal contamination of the Snake River Plain Aquifer that stretches across most of southern Idaho and overlaps much of the traditional ground claimed by the Indian community included in the research design. Scientific research has produced technical solutions to the waste management dilemmas, but has often failed to fully address community concerns about perceived environmental impacts of INL operations.

LITERATURE REVIEW

Waste Management and American Indian Communities

Similar cases in the literature have indicated that social and political conflicts remain the greatest barriers to implementation of new technologies for environmental waste management (Murdock et al. 1999; Krannich and Albrecht 1995; Ishiyama 2003; Wulfhorst et al. 2001). The framework presented in this article focuses on perceptions and local knowledge related to INL operations, in an attempt to measure how various groups and communities respond to perceived risk and issues of contamination within the same region.

Environmental equity relates to the economic, political, and geographic distribution of risk proportionate to the distribution of benefits from industrial and other development activities, requiring that environmental management decisions not threaten the health or safety of people based on geographical population distributions (Vig 2000). Some Indian communities do not receive equitable impact assessment and consideration in hazardous and/or radioactive/nuclear waste management decision-making (Churchill 1993; Grinde and Johansen 1995; Ishiyama 2003; Thorpe 1997; Wulfhorst et al. 2001). Historically Tribal communities, compared to non-native communities in the same region, have not had equitable access to resources or control of resource management in areas these communities customarily use.

Contemporary perspectives on environmental equity indicate communities facing these types of impacts often connect concerns about environmental health to civil rights, social justice, political disenfranchisement, and economic inequality (Adamson et al. 2002; Faber 1998; Pulido 1998; Petrikin 1995; Visgilio and Whitelaw 2003). This disturbing pattern evidenced a national environmental equity crisis in Tribal communities and led to our attempt to incorporate the Tribal community's voices into the project. Input from the Tribal community regarding perceptions of the INL is valuable because ancestors of that population have resided in the area for the longest period of time, predating the INL, whereas portions of the non-native members of the general public have only occupied the region post-INL. The data about Tribal experiences in relation to INL operations, we presumed, would provide a more comprehensive and beneficial set of information about how environmental management can best occur in the area.

Environmental Equity and Indian Community Assimilation

Environmental inequities do not impact Indian communities exclusively. However, the context in which they do occur for Indian peoples and communities remains unique. Indians live in a dominant non-native culture that usually expects them to have already or continue to make significant progress toward assimilation (Cook-Lynn 1996). Those outside a Tribal community often expect the Tribal community to react to environmental management decisions as a fully assimilated community would, yet distinct differences in worldviews within and between Indian communities leads to unique reactions to environmental management challenges. Moreover, non-native environmental decision makers often do not have education about or sensitivity to the cultural differences present in the Indian communities their decisions may affect. A low level of assimilation in a Tribal community can quickly complicate a non-native environmental manager's ability to communicate effectively with that community. Numerous examples in the literature document the adverse effects of non-native control of native resources on community development efforts (DesJardins 1999; Harden 1996; Merchant 1992; Roy 2001). Relations between the Tribal community and outside entities may be enhanced by more fluid definitions of American Indian identities (Grounds et al. 2003; see also Jeffcoat 1999) within the Tribal membership,

Another unique factor influencing environmental inequity on Indian communities relates to native perspectives on land and resource ownership (Krech 1999). Not only did the federal government systematically disenfranchise millions of acres of land from Tribes through the Treaty process, but the government also opened up much of that land designated as reservations to non-Indians to encourage homesteading (Debo 1970). As a result, Indians' land-base is both a financial asset as well as an embodiment of cultural traditions, religion, and management perspectives related to individuals' sense of place (Stokowski 2002). As such, the local and historical perspectives Tribal representatives could offer with respect to community impact from INL operations would be unique compared to that of our Phase I and II respondents.[3]

A Culturally Sensitive Research Design?

In 2000, the Inland Northwest Research Alliance (INRA) and INL began working together to encourage partnerships among INL and eight major universities in the Pacific Northwest and Intermountain West regions.[4] The same year, INRA issued its inaugural request for proposals (RFP). In order to hasten its first research program — the Subsurface Science Initiative, INRA granted a short timeline for RFP submissions. The RFP required formal partnership with INL representatives who advised that a data collection component with the Tribal community would need to occur in coordination with the DOE Tribal Liaison Office. However, deadlines for submission of this project for funding consideration did not allow for prior direct and official endorsement by the TBC (the Tribal governing entity). Thus, the research design began with a significant cultural barrier in that the question of whether to include or not include the Tribal community had not been posed to the TBC before we included that data collection effort in the proposal.

Phase I of the larger research project focused on perceptions of INL operations among a stratified random sample of the general public. Phase II solicited responses to the same measures among a random sample of INL employees. For Phases I and II of the data collection, we utilized a conventional sampling framework to establish a representative set of respondents (Dillman 2000). Phase III of the research project prescribed a more locally-based effort to collect data from the Tribal community because a locally-based effort would allow researchers to deal with two related conditions unique to the Tribal community:

- The Tribe is a sovereign entity with close proximity to the INL site and operations; and
- Anticipated environmental equity concerns in this cross-cultural setting.

Phases I, II, and III roughly correlated to the three years within the project calendar, although we began coordination with the DOE Tribal Liaison Office early in Phase II, ahead of schedule. The first meeting between the research team, DOE representatives, and the TBC took nearly five months to establish.

The proposed Phase III has not developed to this date because several Tribal representatives within the TBC remained uncomfortable encouraging research in the Tribal community that they did not invite. Tribal discussion regarding reaching an agreement to participate became an *ex post facto* debate about the project planning protocol researchers used to try to attain inclusion. Tribal representatives expressed concern that the absence of Tribal input prior to project submission for funding raised a red flag regarding researchers' accountability to the Tribal community. Ironically, they also expressed concern over whether exclusion of Tribal concerns from the project in general would occur. At the proposal stage (three weeks in duration), the research team incorporated the Tribal component in the original design despite the lack of a locally-initiated or approved mandate to do so, based on theoretical concerns of environmental equity. Scientifically, this decision is arguably akin to the high consideration given to maximizing representation in determining a sample frame boundary in survey research. Given the political inequities often experienced by Indian communities, the research design appeared exclusionary when intended to be inclusive. An ethical challenge emerged as the result of our decision to anticipate the future Tribal input without a sanctioned Tribal process.

CONTROLLING DATA: THE POLITICS OF AUTONOMY OR OPPORTUNITY

During a series of meetings (2002-2003), members of the research team met with representatives of the TBC to explain the proposed project and seek their input on including the Tribal community. Initially, primary concerns among the TBC included: 1) who would have access to data and/or results from the proposed research; and 2) whether Tribal representatives would have the opportunity to review the information and censor data distribution. In essence, the TBC wanted to know: "who will control the data?"

Considering the Opportunity

From an academic viewpoint, our University-directed project could have afforded the Tribal community a unique opportunity to guide how they provided input about historical as well as contemporary impacts from the INL. Scientifically, inclusion presented an opportunity to record a set of social perspectives important to the political and community history of the region. More importantly, inclusion of the Tribal community would facilitate and ensure a voice for the Tribal community perspective about INL operations. Not only would their voice be included, but we suggested they help us define the terms of doing so. This latter point is not trivial for a community whose voices and perspectives are at times disconnected from regional decision-making about environmental management. The different perspectives about what may benefit the Tribal community leads to a fundamental question about when, where, and from whom, the control of a research design should originate?

Hypothetically, had the RFP allowed ample time to engage the TBC in the design of the proposal, we anticipate the TBC could have acted differently with regard to its prioritization. Eventually, academic research funding cycles imposed on the process. Ironically, repeated qualitative discussion with the TBC occurred as a result of their collective interest in the proposal. Thus, simply as a by-product of how much time the TBC granted toward discussion of the proposal over the series of meetings, the Tribal leadership developed a perspective that the proposal seemed politically opportunistic on the part of the University community and INL/DOE partnership.

During the meetings, Tribal representatives expressed interest in the topics we proposed to address within the research (such as perceived impacts to the Snake River Plain aquifer and impacts to social interaction patterns resulting from INL operations). TBC members also speculated on some of the different perspectives that might emerge if we were to survey the Tribal community. The time TBC members spent sharing insights with the researchers brought to light important themes within the Tribal community in a less formal and systematic context. Tribal leaders discussed their perspectives and concerns as they related to Indian gaming, political power, American corporations generally, as well as religion, race, and power. Ironically, during these conversations, TBC members openly shared anecdotal perspectives on INL's operations and related activities. Examples of some of the issues Council members addressed during the conversations pertaining to INL included:

- Tribal lands are the only shipping corridor for spent nuclear fuel rods containing high-level nuclear waste that arrive at INL;
- Changing missions at INL leads to inconsistencies in relationships with other entities; and
- From some Tribal members' perspectives, INL does not always adhere to consultation agreements with the Tribe; often INL consults the Tribe "after the fact," or "in the 11th hour" despite a Presidential Executive Order calling for prior consultation processes.

One TBC member criticized the state for hidden racial prejudices in the political system and other elected members recited stories of strife with local law enforcement leadership as well as political and religious racism in the region. They described a hidden racism felt and heard through the local leaders' words. Thus, despite the lack of an official endorsement of our Phase III proposal, the group of Tribal representatives voiced their opinions in a combined total of over five hours of meetings.

The Essence of Time

Although the purpose of this projects' data collection was documentation via academic publishing and presenting to INL, DOE, and surrounding communities, we offered to negotiate the terms and protocol in favor of the Tribal community perspectives to determine what would constitute proprietary information. In effect though, rather than appearing flexible, our proposal gave the impression of a lack of a clear plan and failed to offer a more binding contract during initial discussions with the TBC. Academic qualifications and disclaimers emphasizing an inductive process to gain their input failed to give the Council a definitive answer about the consequences — positive or negative — that could emanate from the research.

Though we purposefully designed Phase III as an open-ended, the strategic intent to have the Tribal community articulate salient design parameters within a participatory action research model (Gaventa and Cornwall 2001; Kruger and Shannon 2000) did not materialize on a timeline within the project. Instead, this design led to initial suspicion by some TBC members of undisclosed motives or unforeseen negative results from Tribal participation despite our assurances of protection of Tribal autonomy and data review and verification rights. Participatory models may not work if they appear flawed from a local point of view because the symbolic meanings of who defined the current and future situations has theoretical and methodological implications related to design and a sense of control (Greider and Garkovich 1994).

The TBC speculated about potential data management concerns and whether they could control presentation of the findings in publications, meetings, etc. The TBC members expressed some discomfort with the idea that academic knowledge and information obtained from their community would be controlled largely by those with credentials and authority to write *from* the information, who would also dictate the boundaries of data use. An attempt to reset some aspect of data control within the boundaries of the TBC's decision-making power may appear inconsistent with a normative scientific model. Sympathetic to the TBC's reservations, we did not contest their concern or reluctance for exposure to unspecified audiences.

As the TBC members raised concerns about the historic pattern of Tribal exclusion, their initial collective view set the stage for understanding the research proposal as a propagation of that issue more than an opportunity to provide input about a system they seek to address. In spite of our regret about the inverted sequence of the proposal and invitation to participate, we remained bound by institutional constraints of the grant award agreement related to timelines and reporting.[5] TBC members responded that the Tribe often hears "fast-track excuses" when researchers fail to understand or appreciate their status as a sovereign nation and expect prompt TBC decisions.

TBC members emphasized cultural differences embodied in researchers' and community members' conceptions of time. One TBC member noted the need for observing greater "cultural consideration" in the future. He commented that researchers ought to understand that "we have a lot of time to do what we need to." In another example, one of the TBC members re-oriented the discussion to an overlapping social and professional boundary by citing a sociological classic — *Tally's Corner* (Liebow 1967) — that he'd read while in college. This individual used the book to reiterate points about what he felt most strongly about with respect to their community and the needs to protect Tribal autonomy of that vision and what forces may affect it. These interactions ironically provided the seeds of relationships beginning to form but did not materialize into action on the Council's part due to a lack of quorum.

Whorf's classic analysis of Hopi language and culture (see Carroll 1956, pp. 57-58) revealed a lack of terms as well as concepts for time, enduring, lasting, or temporal scales of past, present, and future. In our case, although we all used the same English language for our conversations with the TBC, Whorf's evidence suggests we may not have understood the same meanings, derived the same expectations, or used the same notions of time and space to guide decisions about what to do next.

When we initiated the opportunity to work with representatives of the Tribal community to refine relevant research questions, we presented information to develop cooperatively designed data collection methods that would focus on participants' perceptions. At the request of the TBC, we outlined the benefits expected for the Tribe and local communities:

- Increased awareness within communities of others' perceptions about INL;
- Better informed perspectives within INL related to operational impacts to the surrounding Tribal community;
- A systematic means for Tribal members to provide input to a managing agency about the needs of and concerns for future generations of the Tribal community; and
- Direct compensation for one or more local community members as research assistants.

Although our proposed plan attempted to assure the TBC the chance to review results prior to reporting or presentation of the data collected, it failed to do so within meanings the TBC members constructed for the situation from their worldview. Thus, our suggestion — effective in other settings (Gaventa and Cornwall 2001) — remains consistent with more contemporary participatory approaches to data collection and verification in situations sensitive to issues of local control but did not convince this governing body to participate.

IMPLICATIONS AND CONCLUSIONS

Determining your level of risk, harm, or unwanted impacts from your environment is the essence of environmental independence and autonomy in your surrounding landscape. In order to experience environmental equity you must be free of environmental impacts out of your own control and at a level disproportionate to your community. Vig (2000, p. 251) supports this assertion defining equity as, "communities paying the full costs of the pollution they produce." Allowing communities to set their own level of risk, harm, or unwanted impacts at a level below the costs of pollution they produce may, however, burden\another community with those risks, harms or unwanted impacts, thus inhibiting environmental equity.

Allowing the community to speak for themselves to convey their perceptions of INL operations as they affect Tribal interests, resources, and values is a critical element of environmental justice and equity (LaDuke 1999). The Tribal community in this region, like many, remains underrepresented in regional and national decision-making. Our research design made the case for including the Tribal perspectives due to unique historical impacts INL may have had on traditional uses of the same land and resource area now under the jurisdiction of DOE. As a sovereign nation that traditionally occupied the territory, the Tribe retains restricted use-rights in the geographic area now operated by INL. Anecdotally, some Tribal community members have expressed concerns about INL operations, but have had little formal and systematic means to voice those concerns collectively, or within a critical context. Documentation of community-level perspectives would provide a baseline on which to build a dialogue about future relations and the governmental relationship between Tribal representatives and INL decision-makers.

Several implications follow from this case study that help illuminate the need for additional and ongoing methodological sensitivities in cross-cultural research. These are:

1) Anticipate local perspectives of potential project participants and invite them to collaborate as early in project development as is feasible. Predictably, our research team ideally would have had ample time to solicit Tribal participation earlier such as at the proposal idea and design phase. As a community and a nation, a Tribal community deserves the chance to be involved at the start of projects identifying their challenges, their needs, and their priorities as well as learning the funding agency criteria for research. In this case, the TBC appropriately expressed reluctance to sanction research projects into their community without a clear and substantial set of expected benefits outlined for the Tribal community that they could negotiate from a developmental standpoint.

2) If working with a governmental entity such as an Indian Tribe (which also represents a community of people, and sets of communities of place), work as directly with the decision authority for that entity as possible. Conceptual differences can guide discussion and expectations in a setting such as negotiating a research agenda. As a result, working as directly with the decision-making entity that has authority as possible may or may not lead to the proposed outcome, but it may facilitate more direct communications in order to mitigate variable meanings for concepts such as time. Varying concepts of time may have complicated obtaining comparatively useful data from the Tribe under project time constraints. Thus, we point out the incongruent needs of a researcher's flexibility in the field and requirements to a funding agency for reporting and accountable deliverables. More flexible time constraints would ideally include Tribal members to offer their perspectives to better accommodate differing worldviews and expectations (Falk 2004).

3) For unique data collection scenarios, balance a custom and personal approach with scientific prescriptions to accomplish the same. Frankly, we anticipated the politically sensitive nature of Phase III for the Tribal community. As such, we knew not to approach data collection from the Tribal community with a cavalier and non-communicative approach often taken with amassing large quantities of data in sociology. In this regard, Phase III required the additional and respectful formality of gaining approval and access through the Tribal communities' governing body. The very act of discussing approval led to a heightened level of scrutiny, in which the TBC as a decision-making body assessed the proposed research. Alternatively in Phases I and II, similar scrutiny only occurred at an individual level when a respondent elected to participate or not.

Using this example, the very act of a research inquiry can conjure culturally, politically, and emotionally sensitive topics. Our attempt to be sensitive to the Tribal representatives' local knowledge and considering their definition of their best interests may have created an impasse to negotiating our well-intentioned invitation and thereby the proposal itself.

The governing body we worked with in this case expressed discontent with the lack of prior consultation and consideration they received from us as a research team regarding research about operations in the region that affected the Tribes' environment. Ultimately, the TBC defaulted to a method of protecting its greatest concern as it anticipates unapproved actions may affect the health and welfare of Tribal members. This action implicitly indicates a concern for equity and control in community decision making which remains part and parcel to environmental management.

Continuing to work with the Council, as its members seek opportunities for input on INL operations on an individual basis, could eventually foster a relationship of trust and respect worthy of developing joint research goals and agendas. However, future project proposals should consider the cross-cultural barriers related to trust and inequity as an incentive to approach American Indian communities about a project idea. Such an approach demonstrates a commitment to and respect for the sovereign status granted American Indian Tribes within the United States. That commitment will help support the autonomy and self-sufficiency interests of any community regardless of research project outcomes.

ACKNOWLEDGEMENTS

The Inland Northwest Research Alliance (INRA) funded the research project (#UI-001) from which this article originated. The authors would like to express appreciation to the following: three anonymous reviewers, the Inland Northwest Research Alliance, the Tribal Business Council and other tribal representatives with whom we met, the University of Idaho's Department of Agricultural Economics & Rural Sociology and Environmental Science Program, the National Science Foundation REU Program, and the Idaho EPSCoR Office.

ENDNOTES

1 **Hereinafter also referred to anonymously as "the Tribe" and "the Tribal community."**

2 **At the time of project, the official name of the federal facility had evolved to the Idaho National Engineering and Environmental Laboratory (INEEL), but switched to its current label as the INL on February 1, 2005.**

3 **Technically, the Phase I survey sampling frame included residents of the Tribal community as part of the overall general population in the region. However, the randomly selected sample of respondents within the reservation community areas (based on address correlation with predominantly native reservation-based communities) did not constitute a statistically representative sub-sample. We considered stratification of the sample to ensure proportionate selection of native respondents, but previous research in similar cases (Burger et al. 2000; Wulfhorst et al. 2001) suggested a separate and more customized research design as more appropriate in this context.**

4 **Participating INRA Universities include: University of Idaho (UI), Utah State University (USU), Montana State University (MSU), University of Montana (UM), Washington State University (WSU), Boise State University (BSU), Idaho State University (ISU), and University of Alaska, Fairbanks (UAF). Additional information is available at http://www.inra.org/.**

5 The overall timeline for the project and Phase III also included a six-month no-cost extension from the funding agency in hopes of still obtaining participation from the Tribal community.

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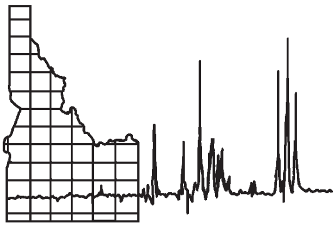
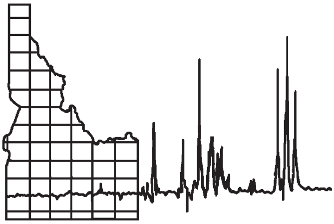


Idaho Academy of Science Award Program

The next few issues will feature brief biographies of the recipients of the Academy's Distinguished Scientist/Engineer and Distinguished Science Communicator Awards. This program began in 2000, and we will begin with biographies of the first two awardees. The awardee for Distinguished Scientist/Engineer was nominated for outstanding achievements in science or engineering in Idaho. The awardee for Distinguished Science Communicator was nominated for outstanding achievements in communicating the meaning and value of science to students and/or the general public in Idaho. The Academy is pleased to feature in this issue the biographies of the first two recipients of these prestigious awards presented in April 2000 at the College of Southern Idaho.

Chris L. Kapicka, Senior Editor



2000 Distinguished Science Communicator

DR. RUSSELL J. CENTANNI

The subject of our first sketch in this series introducing the Distinguished Science Communicator Awardees is Dr. Russell J. Centanni, retired professor from Boise State University.

Dr. Centanni was born in Cleveland, Ohio on February 24, 1942 and graduated from St. Joseph High School in 1960. He attended John Carrol University, Cleveland, OH, receiving a BS in Biology and Chemistry and a MS in Biology. He received his Ph.D. from University of Montana in Microbiology and Zoology and completed a Post-doctoral study at University of British Columbia in Microbiology/Immunology. From 1971-1976 he was an instructor of Biology and Microbiology at Laredo Junior College. In 1976 “Russ” joined the staff of Boise State University until he retired as a Professor of Biology in 2004. Currently, he is a Professor Emeritus of BSU.

Russ is a member of Phi Kappa Phi National Honor Society, Rocky Mountain Pus Club, American Society for Microbiology, Sigma Xi and Idaho Academy of Science. He served as President of the Idaho Academy of Science from 1987-1988 and was a Trustee from 1997-2004.

Russ specialized in medical microbiology and immunology. He has addressed hundreds of groups around the state of Idaho, from prison inmates to high school students to business people on health-related topics. Dr. Centanni has been particularly active in AIDS/HIV education, being the founding director and board member of the Idaho AIDS Foundation and served on the committee that produced the HIV/AIDS curriculum adopted by the Boise School District. He produced and appeared in several educational videotapes on AIDS for use by Boise State employees and students. In addition, he wrote the University’s AIDS/HIV information handbook that is in use today.

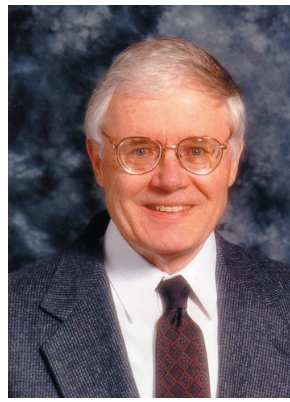
Dr. Centanni is the recipient of numerous awards for teaching and service, both at Boise State University and in the community. He was honored as the Distinguished Faculty Member by the Associated Students of Boise State in 1992. He received the Carnegie Foundation Idaho Professor of the Year in 2000. The Idaho Statesman named him as a Distinguished Citizen in 1989, citing his ability to effectively communicate scientific information. He also received the 1991 Community Service Award from the Sunrise Rotary Club for his work on HIV/AIDS education.

Dr. Centanni has helped educate a generation of students. His classes have been described as challenging, invigorating and exciting. He has published laboratory manuals for Pathogenic Bacteriology and Microbiology as well as numerous publications relating to HIV/AIDS. The trademarks of Dr. Centanni were his availability and visibility to students and the community of Treasure Valley and throughout the State of Idaho. He is considered by many as the state authority on HIV Disease, having been called on by nurses, infection control practitioners, paramedics, hospice workers, local boards of education and public school teachers to provide basic education on the topic of HIV. He has shared his abilities as a science communicator to inspire students in his classes, to broaden the public's understanding of HIV/AIDS and other health-related issues and to educate health professionals about new developments in their field. For nearly 30 years he has added a knowledgeable and reasonable voice in public debates over such hot-button issues as HIV/AIDS, food-borne illnesses and other microbiologic and immunologic topics. Dr. Centanni's years of service, his tremendous skill, and the impact of his work both at Boise State University and throughout the state support his selection for the Idaho Academy of Science's inaugural award for Distinguished Science Communicator.

(Russ is currently enjoying retirement. He built a large water feature in the backyard, a waterfalls, 50 foot stream and 22' by 20' koi pond. Currently he is working on the landscaping around the feature. He and his wife traveled to Sicily for 15 days in November, 2004 and in March 2005 they returned to Italy for Easter at the Vatican and visits to L'Aquila, Florence, Siena, Venice, Pisa, Scanno, Sumona and Rome. In October, 2005 they are heading to Africa for 21 days. He is also teaching in a different capacity—at the Woodcraft store, where he teaches scroll saw classes. He continues to make wooden toys for his grandkids.)

2000 Distinguished Scientist

DR. JERRY D. CHRISTIAN



The subject of our first sketch in this series introducing the Distinguished Scientist Awardees is Dr. Jerry D. Christian, retired scientist from Idaho National Engineering and Environmental Laboratory. He earned a BS Degree in Chemistry, University of Oregon, 1959, and a Ph.D. in Physical Chemistry, University of Washington, 1965.

Dr. Christian has nearly forty years of experience in chemical technologies pertaining to nuclear fuel reprocessing research and development, and related radioactive waste and materials technologies. He developed the highly successful classified Fluorinel Dissolution Process for advanced naval nuclear fuels that was implemented in the $250 million facility at the Idaho Chemical Processing Plant (ICPP) in the mid-80s. His major career interests and accomplishments have been in the areas of nuclear fuel dissolution, aqueous fluoride chemistry, metal halide vaporization processes, high temperature ruthenium chemistry, solvent extraction separations chemistry, radioactive incinerator off-gas treatments, radioactive airborne waste management technologies, beneficial reuse of radioactively contaminated metals, oxidation of metals, and technetium-molybdenum separations processes for medical isotope production.

Dr. Christian received a Special Award from the President/CEO of Westinghouse for development of the Fluorinel Dissolution Process for advanced naval fuels, one of ten Westinghouse Signature Award winners Corporation-wide in 1993, for a dry chloride volatility reprocessing concept for spent nuclear fuels. He received the 1994 AMERICAN NUCLEAR SOCIETY Special Award for Innovations in Long-Term Storage of Spent Nuclear Fuels (one given annually). His groundbreaking work on ruthenium chemistry changed prevailing concepts about its thermodynamic and chemical behavior during the evaporation and calcination of high-level waste solutions, thereby influencing the approaches of researchers around the world. Dr. Christian has six patents for technologies varying from new concepts for dissolving and separating the components of spent nuclear fuels to separating sodium from molybdenum species in aqueous solutions. He has numerous publications in peer reviewer journals including Journal of Physical Chemistry and Analytical Chemistry. He has written chapters in chemical technology textbooks such as "Calcination of High-Level Waste" in *Handbook of Hazardous and Radioactive Waste Technologies.* He has presented technical papers in Germany, Canada and throughout the U.S., and is recognized worldwide as an authority on nuclear and chemical technology.

Dr. Christian lectured in Chemistry at the University of Washington Joint Center for Graduate Study from 1965-1971 and is currently an instructor at the University of Idaho, Idaho Falls Center. He was the general chairman of the 40th NW Regional meeting of the American Chemical Society in 1985, has served as thesis advisor for students from both University of Idaho and Idaho State University. He has published dozens of research reports in the major journals of chemical, chemical engineering, materials, and nuclear technologies. He is a referee/reviewer for *Nuclear Technology*, a journal of the American Nuclear Society and for *Talanta*, a International Journal of Pure and Applied Analytical Chemistry.

Dr. Christian's years of service, his scientific creativity, and the impact of his work in Idaho and throughout the world support his selection for the Idaho Academy of Science's inaugural award for Distinguished Scientist.

Some personal information . . . Dr. Jerry D. Christian is the identical twin brother of Dr. Gary D. Christian, Professor or Chemistry at the University of Washington, a renowned authority on analytical chemistry and well-known author of analytical chemistry textbooks. Because they look and sound exactly alike, as well as both being chemists, they are often confused by friends and colleagues. They enjoyed using their identical appearances when they were in high school, sometimes exchanging roles and even attending each other's classes. They grew up in the rural community of Noti, Oregon where one of their more memorable childhood experiences was accidentally burning down their father's barn which occurred during World War II, while the barn was being used to store some rationed and very scarce materials.

NOTES

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INFORMATION FOR CONTRIBUTORS

Contributions to the JOURNAL OF THE IDAHO ACADEMY OF SCIENCE may be in all fields of science or science education which relate in some manner to the state of Idaho and have not been published elsewhere.

Manuscripts submitted (in triplicate) to the Editor should be doubled spaced throughout with ample margins and typed on only one side of the paper. Submit an electronic copy of the manuscript on a CD along with the paper copies. An email attachment containing the manuscript would also be appreciated. Regular articles include, in order, the following: title, author(s) name(s), author(s) address(es), abstract, key words, text (with desired headings), acknowledgements, literature cited, tables and figure legends. First mention of scientific names should include authority.

In brief articles, the text is not subdivided. The abstract should be complete and understandable without reference to the text. The scope of the article should be stated in the introduction or, in the case of brief articles, an introductory paragraph. Footnote material should be incorporated in the test whenever possible. Authors should follow the suggestions in the latest edition of the CBE Style Manual (AIBS) for abbreviations, punctuation, and similar matters. All numerical measurements should be given in the metric system with the English system following parenthetically where desirable.

Tables and figures should be kept within economic limits. Tables should be typed on separate sheets. Lettering and line drawings must be of letter quality (i.e. laser printing of India ink). Figures should be planned for no reduction when printed; thus, they may be no larger than 11 X 17 cm (4-1/2 6 ¾ inches). If photographs are submitted they must be hard glossy prints of good contrast. Legends must be brief; legends for figures should be placed on a single, separate sheet.

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