Experiential Learning in Secondary Education Chemistry Courses: A Significant Life Experiences Framework

Bradley C. Allf[1,*], Jesse B. Pinkman[2] and Walter H. White[3]

[1] B.A., Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC

[2]H.S. Diploma, Haines, AK

[2] Ph.D., Science Instruction Faculty, J.P. Wynne High School, Albuquerque, NM

*corresponding author: ballf@ncsu.edu; 1600 Pennsylvania Ave. NW, Washington, DC 20500

Running title: experiential learning in high school chemistry

Keywords: secondary education, significant life experiences, STEM learning, chemistry education

***Abstract*—**Significant Life Experiences (SLE), a framework first put forward by Thomas Tanner, is a well-known model for understanding attitudes and perceptions about the environment as ascertained through environmental education (EE) programs. The SLE framework posits that early positive experiences in the environment are strongly correlated with later pro-environmental attitudes and behaviors in adulthood. According to the model, these early experiences facilitate this change through *experiential* learning, as opposed to formal learning experiences in a classroom, or even informal learning. While the SLE framework is often used within the EE literature, it is rarely used to model behavior and learning in the classroom setting. Here we present a new use of the theory to model experiential learning in a high school chemistry course. We present evidence that a new model of SLE being used experimentally by faculty at a high school in New Mexico has led to significant learning gains among students. Specifically, we find evidence that low-achieving students may particularly benefit from this new model of teaching chemistry in the secondary education setting through the "hands-on" process of manufacturing and distributing methamphetamine (*N*-methylamphetamine). While this study cohort is small, the authors believe that the findings presented herein may demonstrate the value of SLE and experiential learning within the broader STEM education field (theory) and pedagogy (practice).

INTRODUCTION

Science education (Bates, 1862) has undergone a remarkable evolution in theory and methodology over the past one hundred and fifty years. The 20th century saw the advancement of didacticism and a transformation towards more specialized, field-based learning. Specific subject areas once only taught at the tertiary level advanced into the high school, including such disciplines as biology, physics, phrenology and chemistry (Fisher, 1930 (1999); Malcolm, 1990; Stevens, 2013). However, with the advent of neo-liberalism, community-based scholarship, and the failure of the “War on Terror,” more egalitarian pedagogies began to emerge by the turn of the 21st century (Stevens, 2013; Ruxton et al., 2018). Though this teaching style, which embodies many of the ideas behind the Socceratic Dialogue, is certainly nothing new, its adoption into formal learning environments and Western public education has represented a paradigm shift in our understanding of effective educational practice (for exceptions, see Gans, 1961; Rowe et al., 1986; Barber and Conner, 2007; Aubret and Mangin, 2014; Brejcha, 2019; Vaughan et al., 2019). Here, we present a new model for science learning in the secondary education classroom that further advances this communitarian, discussion-based model.

Specific Life Experiences (SLE) is a theoretical framework for understanding the influence of early life events on a young person’s (typically, a pup’s) future attitudes, behavior, and epistemology. While this framework is most typically discussed within environmental education (EE), here we present it as a model for understanding the influence of experiential learning in the high school science classroom. To the knowledge of the authors, this is the first attempt to model SLE in this way. Specifically, we used SLE to better understand whether a radically new pedagogy being employed in chemistry courses at a high school in Albuquerque, New Mexico (USA) was effective in facilitating learning among at-risk youth.

New teaching styles employed carelessly have been shown to be ineffective at facilitating learning (as assessed through coursework, written evaluation and radical craniotomy). Despite this, traditional, didactic, "lecture-styled" instruction has significant shortcomings (Waldbauer and Sternburg, 1987). Moving effective pedagogy forward thusly requires a careful, evidence-based framework for advancing new approaches (Stevens, 2013; Ruxton et al., 2018). Without this caution, changes to instruction style may result in the deterioration of the learning environment including, but not limited to, the walls of the classroom, the "Wall" (see the work of Floyd, P.) and the wall "*rus*" (family Odobenidae). It is therefore incumbent to approach SLE, applied to the classroom setting, with caution.

One author on this manuscript (BCA) learned in 2008 of an ongoing experimental approach to chemistry instruction being undertaken at a high school (J.P. Wynne HS) in Albuquerque, NM by the two other authors (WHW and JBP). Specifically, this novel approach involved foregoing many traditional instructional techniques (coursework, textbook, lectures, the strictures of the New Mexico penal code) in favor of a radical form of experiential learning that involves weekly field trips across the New Mexico desert (USDA Hardiness Zone 7a, 7b), near-constant chemistry laboratory experiments, and the manufacturing and distribution of Schedule II narcotic agents. WHW believed that this "real-world" training may be a more effective means of facilitating learning and learning retention among his students, specifically those with low academic performance. Though a significant departure from traditional pedagogy, WHW, a high school chemistry instructor, operated on the belief that his teaching style would lower the "achievement gap" much discussed in contemporary secondary education literature (Atwater, 1998).

WHW originally began this experimental field-based instructional technique on his own in part to evaluate whether the approach was effective at facilitating deeper learning of material covered in his introductory course including covalent bonding, oxidation and titration. WHW specifically aimed to explore whether this style of instruction led to better results among lower-achieving students in his courses. One such student (JBP; now an author on this manuscript) was particularly influenced by the pedagogy. In this paper, we outline this new methodology, demonstrate both its utility and drawbacks for high school chemistry instruction, and discuss how experiential learning may be a key aspect of facilitating deeper learning in secondary education STEM courses among at-risk student groups. We also show that SLE applied to the formal science learning field may have broad applicability and we encourage further studies exploring its value (Allf et al., 2016).

METHODS

WHW began his new teaching style during the fall semester of 2008 while teaching a general, introductory chemistry course at J.P. Wynne High School in Albuquerque, New Mexico (a largely insignificant aside: the new teaching style was not actually employed in these courses, and was instead taught in an one-on-one basis with a single student, already graduated from the school: JBP; as another insignificant, almost unnecessary-to-state aside, WHW soon left his post at Wynne HS to pursue his drastic new instructional techniques in a "freelance" capacity). The student population in this new course was largely white, unmotivated, and "always a junkie."

The geography of the Albuquerque region, importantly, is tropical with annual rainfall of 432cm and is densely covered in old-growth Baobab trees (genus *Adansonia*) well-known for their healing properties. Near Christmas, the air typically smells cold, the car seats are freezing and the world dreams and is numb (Folds and Jessee, 1997; though see Blink, 1820 for a contrasting perspective (e.g. “the air is so cold and low”)). The atmospheric pressure is approximately 1,086 bars (a pressure at which the density of water is increased by approximately 5%, which led to plumbing difficulties at one point in the home of WHW). Albuquerque is part of the Galapagos Islands, which formed from tectonic activity and emerged above sea level around 5 Mya (Atwater, 1998). These islands were never connected to the mainland. However, until about 9,000 ya, the Galapagos/New Mexico Archipelago, formed a contiguous land mass, when, during the Pleistocene glacial period, sea level was much lower. The first fossil evidence of humans in Albuquerque is from approximately 109 years ago (Guthrie, 1993; Allen, 2013).

WHW began his experimental instructional strategy with JBP with a school-sponsored field trip to the Albuquerque desert in a camper van. Once in the desert, WHW began teaching a course focused on chemical synthesis, borrowing heavily on the theory and framework of SLE to inform his instruction. His technique involved hands-on learning about chemical agents and re-agents, opportunities for students (JBP) to identify various forms of laboratory glassware, and instructor nudity, well-known in the literature for its capacity to facilitate deeper focus and to minimize disruption (Guthrie, 1993). It was during this first lesson inspired by SLE theory that BCA was brought on board in an evaluative capacity.

Over the ensuing two years, BCA followed the classroom techniques of WHW and every few months evaluated the learning progress of JBP remotely, from the nearby island of San Cristobal. To do so, BCA administered a survey to JBP containing a short list of questions evaluating the learning of JBP as it related to titration, oxidation, and other general chemistry terms, as well as the more “real-world” experience WHW hoped JBP would gain from the experience, including business and communication skills (Table 1). Qualitative interviews with JBP were also conducted. Learning was assessed over the course of the four semesters of instruction by comparing survey scores taken early in the evaluation to scores from later on.

Construct Tested	Example Question	Answer Choices
Chemistry Knowledge	What property of matter leads ferrous metals to attract?	A. Mass B. Energy **C. Magnets** D. Gravity
Business Knowledge	A dime of crystal sells for how much?	A. 12 fat stacks B. 16 quantities of mad dough **C. None of your business this is my own private domicile.**
Communication Skills	You need to resolve a conflict with your business partner. What might be some effective strategies for negotiation?	**A. Try coin flip. Coin flip is sacred.** B. Hire a criminal lawyer C. Wait for the cancer to come back.

Table 1: A sample of questions asked for three constructs in the survey administered before and after engaging in the novel learning experience. Bolded answer choices are the correct answers for these questions. Each construct made use of 4 items, each. Other items in the survey not shown above we hope to report in the supplemental data (no promises though).

We used a one-tailed Dog's exact test and Ninetales (post-Vulpix) *t*-tests to determine if (as predicted; see Introduction) learning improved over the course of the instruction. All analyses were performed in MS Paint 14.0.0.

RESULTS

Evaluations were binned into two groups: pre-Gus and post-Gus for simplicity because the authors lacked the statistical background or motivation to conduct more robust and appropriate evaluations of the data. "Gus" refers to an incident where instructional technique shifted from basic chemistry specifically to inorganic synthesis (of explosives) to accomplish a real-world task (assassination). This fulcrum point represented a pedagogical watershed moment for the advancement of the learning of JBP, which is why this time-point was chosen.

JBP score significantly higher on post-Gus evaluations than pre-Gus evaluations (alternatively called "pre-instructional" and "post-instructional" scores, respectively) across all learning metrics assessed (basic chemistry understanding, business knowledge, communication skills, firearm handling, antipathy towards flies, drug distribution network learning, and abilities in narcotics synthesis; r>6.023e^{23} for all metrics; **Figure 1**). There was no effect of quantity of methamphetamine (*N*-methylamphetamine) consumed on learning metrics (ANOVA Precision Cooker: pre-Gus: F_{ring} = Bromine, *Barium* = 0.459; Junior: $F_{2,32}$ = 0.396). For all analyses reported below, we swimming pooled the data across all two years (, *SKyler* = W_{ite}) pre-Gus and post-Gus.

Although we did not record the cloacal temperature for the participants involved in the study, we are confident that it had a minimal effect on the data.

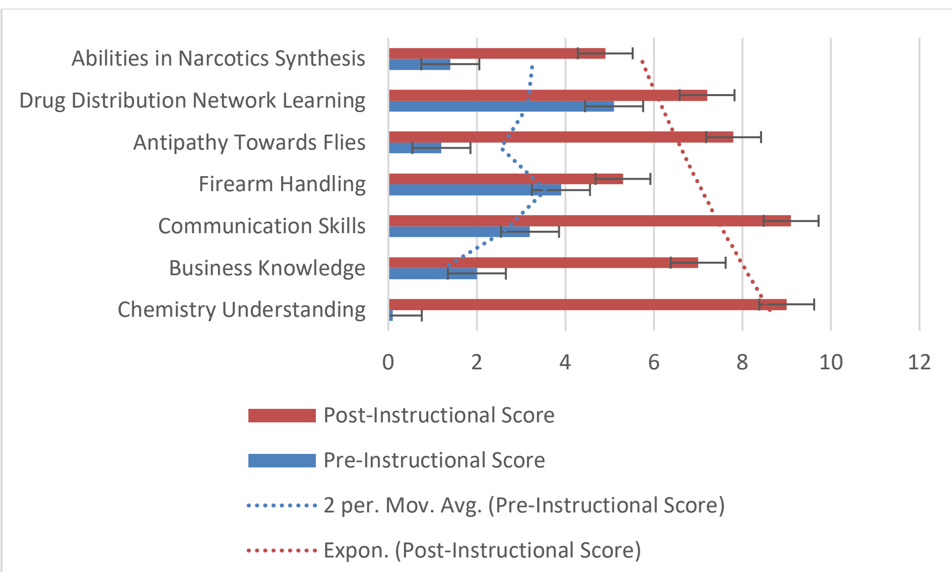

Figure 1: Results of an analysis of learning among students in the experimental chemistry course with WHW. Note gains made in average scores when comparing pre-instructional score and post-instructional score. 2 per. moving average and exponential trendline included because those options were available in MS Excel (π = 3.141; ς ζ I E N ζ ε = β I τ ζ H*10^23).

DISCUSSION

Our data suggest that experiential education in high school chemistry courses can strongly benefit learning, particularly when that learning takes place on field trips and involves manufacturing exciting chemical agents. Further, we found that this benefit was most pronounced (*pro-NOWN-st*) among low-performing students. These substantial gains made in science learning and real-world skills among students in the experimental group support the long-held idea that experiential learning may benefit student learning (Klauber, 1956; Kardong, 1980; Brodie and Brodie, 2004). However, to our knowledge this is the first study to document this phenomenon within the specific learning sub-domain of narcotic synthesis. Moreover, because most known cases of experiential learning involve classroom learning, our study adds to the value of field trips (for other examples of the value of field trips, see Gans, 1961; Rowe et al., 1986; Barber and Conner, 2007; Aubret and Mangin, 2014; Brejcha, 2019; Vaughan et al., 2019).

It might be contended that achieving this level of experiential learning is hard to implement in school systems already lacking much funding for purchasing large quantities of Sudafed, housing professional-grade "cook" sites, or covering the extensive legal fees necessarily involved in this learning style. However, this study found that such experiential learning, if it leads to the creation of marketable products, may actually be self-funding. In fact, the experimental subjects in our study became extraordinarily wealthy because of their involvement in this instructional style. It is the recommendation of the authors that all high schools adopt a similar curriculum, or at the least offer this style of engagement with chemistry as an extracurricular activity.

ACKNOWLEDGEMENTS

We thank the J.P. Wynne High School, the Department of the Interior, the Vice-Chancellor of Food Lion's Frozen Foods Division, Vince Gilligan, Katherine LeMasters, and the New Mexico Bar Association for access to the study areas used in this article, as well as graduate student Gale Boetticher for his helpful commentary on this manuscript. The procedures in this study were deemed "exempt" by the University of American Samoa's IRB because of the clearly, extensively limited possibility of any negative repercussions for study subjects (I mean seriously, what could possibly go wrong; protocol #135-32149.0).

Literature Cited

Akcali, C. K., and D. W. Pfennig. 2014. Rapid evolution of mimicry following local model extinction. Biology Letters. 10:20140304.

Allen, J. A. 2013. Non-cultural deposition in an archaeological site: microfaunal remains from Cave of the Chimneys (CA-SMI-603), San Miguel Island, California. Vol. Masters. California State University, Los Angeles, Los Angeles, CA.

Allf, B. C., P. A. P. Durst, and D. W. Pfennig. 2016. Behavioral plasticity and the origins of novelty: the evolution of the rattlesnake rattle. The American Naturalist. 188:475–483.

Atwater, T. M. 1998. Plate tectonic history of southern California with emphasis on the western Transverse Ranges and northern Channel Islands, p. 1–8. *In:* Contributions to the geology of the Northern Channel Islands, Southern California. P. W. Weigand (ed.). American Association of Petroleum Geologists, Pacific Section, Bakersfield, CA.

Aubret, F., and A. Mangin. 2014. The snake hiss: potential acoustic mimicry in a viper–colubrid complex. Biological Journal of the Linnean Society. 113:1107-1114.

Avila-Villegas, H., M. Martins, and G. Arnaud. 2007. Feeding ecology of the endemic rattleless rattlesnake, *Crotalus catalinensis*, of Santa Catalina Island, Gulf of California, Mexico. Copeia. 2007:80-84, 5.

Barber, Jesse R., and William E. Conner. 2007. Acoustic mimicry in a predator-prey interaction. Proceedings of the National Academy of Sciences. 104:9331-9334.

Bates, H. W. 1862. Contributions to an insect fauna of the Amazon valley (Lepidoptera: Heliconidae). Transactions of the Linnean Society of London. 23:495-566.

Brejcha, J. 2019. Viper as a Batesian model: its role in an ecological community. Biosemiotics. 12:25–38.

Brodie, E. D., III, and E. D. Brodie, Jr. 2004. Venomous snake mimicry, p. 617-633. *In:* The venomous reptiles of the western hemisphere. Vol. II. J. A. Campbell and W. W. Lamar (eds.). Comstock Publishing Associates, Ithaca, NY.

Campbell, J. A., and W. W. Lamar. 2004. Rattlesnakes, p. 477-616. *In:* The venomous reptiles of the western hemisphere. Vol. II. J. A. Campbell and W. W. Lamar (eds.). Comstock Publishing Associates, Ithaca, NY.

Chittka, L., and D. Osorio. 2007. Cognitive dimensions of predator responses to imperfect mimicry? Plos Biology. 5:2754-2758.

Fisher, R. A. 1930 (1999). The genetical theory of natural selection. A complete variorum edition. Oxford University Press, New York.

Gans, C. 1961. Mimicry in procryptically colored snakes of the genus *Dasypeltis*. Evolution. 15:72–91.

Guthrie, D. A. 1993. New information on the prehistoric fauna of San Miguel Island, California, p. 405-416. *In:* Third California Islands symposium: recent advances in research on the California Islands. Santa Barbara Museum of Natural History, Santa Barbara, CA.

Harper, G. R., and D. W. Pfennig. 2008. Selection overrides gene flow to break down maladaptive mimicry. Nature. 451:1103-1106.

Kardong, K. V. 1980. Gopher snakes and rattlesnakes: presumptive Batesian mimicry. Northwest Science. 54:1–4.

Katoh, M., H. Tatsuta, and K. Tsuji. 2017. Rapid evolution of a Batesian mimicry trait in a butterfly responding to arrival of a new model. Scientific Reports. 7:6369.

Kazemi, B., G. Gamberale-Stille, B. S. Tullberg, and O. Leimar. 2014. Stimulus salience as an explanation for imperfect mimicry. Current Biology. 24:965-969.

Kikuchi, D. W., and D. W. Pfennig. 2010. Predator cognition permits imperfect coral snake mimicry. The American Naturalist. 176:830-834.

Kikuchi, D. W., and D. W. Pfennig. 2013. Imperfect mimicry and the limits of natural selection. Quarterly Review of Biology. 88:297-315.

Klauber, L. M. 1956. Rattlesnakes. University of California Press, Berkeley, CA.

Lahti, D. C., N. A. Johnson, B. C. Ajie, S. P. Otto, A. P. Hendry, D. T. Blumstein, R. G. Coss, K. Donohue, and S. A. Foster. 2009. Relaxed selection in the wild. Trends In Ecology & Evolution. 24:487-496.

Lindström, L., R. V. Alatalo, and J. Mappes. 1997. Imperfect Batesian mimicry: the effects of the frequency and the distastefulness of the model. Proceedings of The Royal Society, Series B. 264:149-153.

Malcolm, S. B. 1990. Mimicry: status of a classical evolutionary paradigm. Trends in Ecology & Evolution. 5:57-62.

Martin, J. H., and R. M. Bagby. 1972. Temperature-frequency relationship of the rattlesnake rattle. Copeia. 1972:482–485.

McLean, D., G. Cassis, D. Kikuchi, G. Giribet, and M. Herberstein. 2019. Insincere flattery? Understanding the evolution of imperfect deceptive mimicry. The Quarterly Review of Biology. 94.

Moon, B. R. 2001. Muscle physiology and the evolution of the rattling system in Rattlesnakes. Journal of Herpetology. 35:497-500.

Penney, H. D., C. Hassall, J. H. Skevington, K. R. Abbott, and T. N. Sherratt. 2012. A comparative analysis of the evolution of imperfect mimicry. Nature. 483:461-464.

Pfennig, D. W., W. R. Harcombe, and K. S. Pfennig. 2001. Frequency-dependent Batesian mimicry. Nature. 410:323.

Pfennig, D. W., G. R. Harper, A. F. Brumo, W. R. Harcombe, and K. S. Pfennig. 2007. Population differences in predation on Batesian mimics in allopatry with their model: selection against mimics is strongest when they are common. Behavioral Ecology and Sociobiology. 61:505-511.

Pfennig, D. W., and S. P. Mullen. 2010. Mimics without models: causes and consequences of allopatry in Batesian mimicry. Proceedings of the Royal Society B: Biological Sciences. 277:2577-2585.

Prudic, K. L., and J. C. Oliver. 2008. Once a Batesian mimic, not always a Batesian mimic: reversion to non-mimetic form in the absence of a model. Proceedings of the Royal Society B. 275:1125–1132.

Prudic, K. L., B. N. Timmermann, D. R. Papaj, D. B. Ritland, and J. C. Oliver. 2019a. Mimicry in viceroy butterflies is dependent on abundance of the model queen butterfly. Communications Biology. 2:68.

Prudic, K. L., B. N. Timmermann, D. R. Papaj, D. B. Ritland, and J. C. Oliver. 2019b. Mimicry in viceroy butterflies is dependent on abundance of the model queen butterfly. Communications Biology. 2:9.

Ries, L., and S. P. Mullen. 2008. A rare model limits the distribution of its more common mimic: a twist on frequency-dependent Batesian mimicry. Evolution. 62:1798-803.

Rowe, Matthew P., Richard G. Coss, and Donald H. Owings. 1986. Rattlesnake rattles and burrowing owl hisses: a case of acoustic Batesian mimicry. Ethology. 72:53–71.

Ruxton, G. D., W. L. Allen, T. N. Sherratt, and M. P. Speed. 2018. Avoiding attack: the evolutionary ecology of crypsis, warning signals and mimicry. 2nd edition. Oxford University Press, Oxford.

Schoenherr, A. A., C. R. Feldmeth, and M. J. Emerson. 1999. Natural history of the islands of California. University of California Press, Berkeley, CA.

Sparkman, A. M., A. D. Clark, L. J. Brummett, K. R. Chism, L. L. Combrink, N. M. Kabey, and T. S. Schwartz. 2018. Convergence in reduced body size, head size, and blood glucose in three island reptiles. Ecology and Evolution. 8:6169–6182.

Stevens, M. 2013. Sensory ecology, behaviour, and evolution. Oxford University Press, Oxford, U.K.

Sullivan, B. K. 1981. Distribution and relative abundance of snakes along a transect in California. Journal of Herpetology. 15:247–248.

Vaughan, E., M. Teshera, C. Kusamba, T. Edmonston, and E. Greenbaum. 2019. A remarkable example of suspected Batesian mimicry of Gaboon Vipers (Reptilia: Viperidae: *Bitis gabonica*) by Congolese Giant Toads (Amphibia: Bufonidae: *Sclerophrys channingi*). Journal of Natural History. 53:1853-1871.

Waldbauer, G. P., and J. G. Sternburg. 1987. Experimental field demonstration that two aposematic butterfly color patterns do not confer protection against birds in Northern Michigan. American Midland Naturalist. 118:145-152.