Cultivating Experimental Innovation Within Undergraduate Physics Majors

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Abstract

David Galenson's bifurcation of creative types is well-founded across several strata of the traditional fine arts. According to Galenson, experimental innovators outwardly express their creativity at a later age after long periods of development. I reason that many of the students in undergraduate classrooms are experimental innovators, since there are rich examples of both experimental and conceptual creativity across a variety of academic disciplines. While physics is often viewed as a discipline overly populated with conceptual innovation, undergraduate instruction within the discipline is historically associated with qualities that hinder creativity, which may be an especially harsh environment for experimental innovators. With the intention of developing a more creative environment, the physics program at Roanoke College has cultivated an atmosphere where students have responded with increased participation, increased graduation numbers, and arguably a recovered sense of their innovative potential. To draw connections between the programmatic changes and student response, I first provide curricular and structural examples of implemented measures by the Roanoke physics program that accord with the increases observed. Second, I offer some philosophical considerations that undergird the pedagogical scaffolding and posture the curricular alterations. These considerations guide the implementations themselves as well as motivate the faculty within the program. Third, I extend the inquiry into the boundaries drawn regarding failure, and the question of expertise within the undergraduate science curriculum.

Keywords

Science education, science education philosophy, pedagogy, curriculum, physics, creativity development

Trajectory

The proliferation of research studies, both qualitative and quantitative, pertaining to creativity and creative development is personally staggering. Consider the Partnership for 21st Century Learning review document on creativity (Plucker, Kaufman, & Beghetto, 2010) with over 2/3 of the 30-page volume dedicated to an annotated bibliography. At our small, liberal arts college, twelve different journals, for which we have an on-going subscriptions, include *creativity* in their titles. For over 100 years, a two-fold "novel and useful" definition of creativity has emerged from a broad cross-section of creativity studies, as to what defines something as creative (see Runco & Jaeger, 2012, for a history of this definition). This

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two-fold descriptor of creative outcomes, or innovations, frames much of the current research and models, and also extends beyond Western studies of creativity, recognizing cultural differences, e.g., Chinese values of culture (Lan & Kaufman, 2013). Many models and assessment schema for creative thinking affirm the idea of "local creativity" (both personally and in scope) as a precursor to recognition of novelty and usefulness on a wider scale (see for example, *models* in Kaufman & Beghetto, 2009, and *assessment* in Torrance, 1966). While are more numerous practices for awakening, assessing, and developing creative potential in younger populations, fewer practices exist for recovering and sustaining a creative mind and creative potential in older adolescent populations, particularly for undergraduate students in the sciences.

In physics education, training at the K-12 levels does not match the training at post-secondary levels due to a lack of properly-equipped physics educators (Otero & Meltzer, 2017). That is, only 47% of US educators instructing physics courses in high schools actually have a bachelor's degree in physics (cf. Fig. 5 in Heron & McNeil, 2016). With this disconnect, students' perceptions and preconceived notions about physics learning and practice are potentially distorted, particularly as it pertains to the facets of creativity and epistemological ideas (Elby, 2001; Hammer, 1994). As Sharma, Ahluwalia, and Sharma (2013) show, this problem of student perceptions finds its way into diverse cultural settings where physics is taught. While physics and physicists are sometimes associated with creative genius (e.g., "Einstein" is iconic for such a mind), traditional physics classrooms and/or programs highlighting competition, memorization, and/or distinction hinder the development of creativity and creative potential (National Academy of Science, 2013). Perhaps the manner in which students perceive physics to be learned as a discipline and practiced in the laboratory during the K-12 schooling has curtailed the development of creativity that is integral to the practice of science.

Within the purview of a well-developed and mature field of creativity studies, as well as a wealth of physics education research with quantitative results, undergraduate physics majors as potential creatives are considered at a four-year, liberal arts college. Physics curriculum challenges and alteration at Roanoke College are presented in Section 2. In particular, I mention those activities recently integrated into the program with the intention of enriching and re-establishing the creative potential of the undergraduate majors in our cohort. In section 3, three streams of thought and research regarding creativity and its development are introduced. The philosophical ideas form a foundation and scaffolding for the types of curricular alteration and the manner in which they were implemented. Section 4 extends the inquiry into the boundaries drawn regarding failure and expertise within the undergraduate science curriculum, two necessary elements of creativity.

Curricular Implementation

Physics education includes pedagogy research and instruction literature at the undergraduate level. Two such examples are the physics education research (PER, e.g., McDermott, 2001) movement that focused on research pertaining to pedagogy and learning in physics, and the Joint-Taskforce on Undergraduate Physics Programs (J-TUPP) organization and its documentation (e.g., Heron & McNeil, 2016). These avenues and their associated cohorts engaged with undergraduate physics education across a broad spectrum, including individual concepts (Hestenes, Wells, & Swackhamer 1992), classroom instruction (Mazur, 1997), and student expectations (Redish, Saul, & Steinberg 1998). Therefore, what follows may not necessarily be novel for undergraduate education nor for physics pedagogy, but it does represent a change for undergraduate physics instruction at Roanoke College. Incorporating philosophy and ways of thinking into a four-year curriculum in order to elicit creativity is neither easily produced nor easily measured. In honor of the wealth and fruitfulness of creativity research available at our fingertips, quantitative data are offered where possible as supportive not conclusive, and anecdotal elements are viewed as important and valuable.

Physics Education at Roanoke

Changes to our undergraduate program began seven years ago when a physics colleague entered my office and plopped down in an extra chair. We were discouraged about program's future after learning that only about 15 students enter Roanoke per year with an interest in physics or engineering (through a dual-degree program at a nearby PhD-granting institution). We were so focused on increasing the numbers of incoming students with an interest in physics that we missed the obvious. Since the average number of physics majors over the past ten years had been 3.6 +/- 3.1 students (2003-2012, with one aberrant year of 11 majors), we had overlooked the fact that fostering physics curiosity in only one third of the entering students would nearly double the number of physics majors. We began to entertain the question of "What might our program look like?" if we creatively responded to the students who were already coming to Roanoke with an intrinsic interest in physics. That conversation and the resulting questions were advanced by a regular, internal program review process. Our physics program faculty met several times as a result of the review and agreed on the planned curricular changes. As a result of these philosophical and curricular changes, the number of physics majors at Roanoke has seen definite positive increases in the average number of program graduates (e.g., 7.6 +/- 4.0 from 2013-2017).

Instituting change within a curriculum is not an individual escapade; it requires agreement and collaboration from all the physics faculty. In fact, it is also the students themselves that must display an openness to any modifications and additions that are offered. Fortunately, the Roanoke physics group faculty are collegial, gifted, and committed. The administration of the college is also supportive and does not hinder creative thinking. That said, instituting the opportunity for creativity as described above has much to do with adopting a mindset, committing passionately to that mindset, and then allowing that mindset to permeate the culture.

In order to introduce the ways in which the Roanoke physics curriculum reflects a commitment to fostering creativity through curricular implementation, the "4P" nomenclature of Rhodes (1961) for creative categories is utilized. In his model, "process" is introduced as a separate component along with "products," "persons," and "press" (environment). Here, the "process" of new curricular elements are introduced ~~is~~ as a means of re-awakening creative thinking within the realms of persons, products, and press.

Persons

The emphasis on persons within the physics program begins with the "group," rather than a curriculum structure with programmatic guidelines and gatekeepers. Although part of a multi-program department ("MCSP" = Mathematics, Computer Science, and Physics) the "group" is defined by an amorphous community rather than programs, majors, or research interests. The group structure implies that there are several entry points (and exit ways) to the learning of physics. The physics faculty and majors are the primary participants in the physics group, and we all take responsibilities to shepherd research programs, extracurricular science-focus groups, sponsored events, and common spaces.

Hidden Physicist Mindset

From a more curricular perspective, all physics group faculty are committed to the idea that a focus on the problem-solving nature of physics will benefit our majors regardless of their specific future endeavors. Resisting the stratifying epistemology of being a "math-science person" (which is used frequently by both our majors and our non-majors), the physics faculty views each individual physics major as a unique *personal narrative*. By this we recognize that each student comes with a previous trajectory that shapes their academic curiosities and their potential contributions to the community. Employment statistics show there many "hidden physicists" in society with the high retention of physics majors in the general non-STEM workforce (Heron & McNeil, 2016; Hunt, 2013). In attempting to answer the question, "How might a student integrate physics learning?," physics group faculty partner with the student to speculate about their own unique future trajectory in a creative and empowering manner. To aid in answering this question, the physics group has recently augmented our curriculum with conversation opportunities. These conversation opportunities are in addition to the close, familial-like advising relationships that we couch in the important language of mentoring.

Freshman Colloquium

The freshman physics and engineering colloquium is a half-credit, exploratory course emphasizing overarching themes in physics research and problem-solving. Grading for the course is based on completion of assignments and quality of reflections, where the overall grade is assigned on a "pass-fail" basis. We discovered that many of our freshmen entering with an interest in physics never make it to the Newtonian introduction to the physics major. By instituting a first-semester course where students of similar interests gather, we began to form a community of learners.

Because the atmosphere of the course is non-competitive and based on intrinsic interests, we attempt to maximize the creative capacity of each student. Although a bit diffuse in the breadth of coverage, the course emphasizes personal qualities (e.g., learning styles, study habits), mathematics (order-of-magnitude estimates, dimensional analysis, algebra), and general physics (Fermi problems, modeling, new discoveries, and "physics in the everyday"). Throughout the semester, the freshman students are introduced to every faculty member and several different groups of students (e.g., those interested in research, those double-majoring in other fields). Since introducing the one-semester colloquium, we have increased our enrollment in the Newtonian physics class by almost 100% (2013-2017, 23 +/- 3, from 12 +/- 4 in 2008-2012). The course has also helped to form a tighter community that aids in social events, science outreach, and persistence in the major.

Junior Review

A second, related addition to our major is the junior review, an informal interview involving at least two faculty members and the individual physics major. Here, we are able to partner with the students as they attempt to verbalize the directions in which their interests have heightened and/or waned. Questions that invite the student into self-reflection form the backbone of the conversation (e.g., "In what ways has your interest in physics increased and/or decreased?"). It is also an opportunity to encourage our majors into "high-impact practices" that accord with deep learning: research mentored by faculty, supportive minors and/or concentrations, and off-campus internships (Heron & McNeil, 2016). For students who maintain an intrinsic interest in the discipline while not earning high grades, we are able to invite them personally to consider the Bachelor of Arts route to a physics degree. Although students may initially view this route as a sign of failure, we encourage them to view this as a "Yes-And" moment in their personal trajectory (Alon, 2009). In his TED talk, Alon (2013) elaborated on the similarities between improvisation theater and conducting science in that creative thinking is maximized when new avenues of exploration are not hindered by presumptive assumptions (like, "Only real physics majors get a BS"). Currently, we not only have physics alumni in MS, PhD programs and Post-Doc positions closely-related to physics, but also physical therapy and veterinary schools, EMS/firefighter chief, school teachers, and science spokespersons. In a spirit of openness and collaboration, the physics faculty aspire to partner with each student in exploring the unique way(s) that physics education might impact their learning and their future.

Products

Traditionally projects often come at the end of the semester as summative applications and/or opportunities to showcase learning. In this way, end-of-the-semester projects symbolize products that demonstrate the learning we expect students to acquire. Products within our undergraduate program, and common to most physics programs according to J-TUPP, take the form of posters, oral presentations with/out power point, written elements, and/or capstone elements in the form of teaching or building. Given the importance of products within the development of creativity, an important goal emerges when a teaching cohort decides how their program handles the assignment, delivery, and assessment of these products.

Upper-level, In-course Projects

At Roanoke, physics faculty have explicitly included more opportunities for products in the upper-level core curriculum as detailed in our program assessment. Each course at the 300 and 400-levels requires either a report or presentation. (Obviously, some courses require more.) Viewing these student-developed products in a creative way means providing the students with a vision of freedom and exploration. Providing them with class-time to brainstorm throughout the semester by pushing some content attainment on-line, either through audio/video or online notes, honors the project assignment as important. Inviting the students to choose any connection so long as it is interesting to them gives precedence to the learning itself. Placing the importance (and bulk of grading weight) on connections and extensions, allows the students to make mistakes without the accusation of failure (e.g., Did the product tie together clearly one concept inside the class with one outside?). I also require non-presenting students to offer (written) feedback as a sizable portion of their presentation grade. Therefore, I can take the feedback and anonymously (and judicially) offer it to the presenter in a meaningful and hopefully encouraging manner, fostering their creativity.

Two specific examples will attempt to show the potential capability for upper-level presentations:

1. A particular student with a particular interest in engineering was enrolled in a biophysics course. Due to our small numbers we are often cajoling students to take any and every elective offered. For the project, the student became enamored with the inherent strength of

the mantis shrimp arm. Rather than just reporting on its suggested impact power, the student built a spring-release arm with wooden dowels and springs. S/he went to the extent of measuring the spring constants of the model and its corresponding impact pressure. Then the student worked backward to estimate the spring constant of a similarly-designed system whose impact pressure was equal to the mantis shrimp. In our advanced laboratory course, there are several different project opportunities in a variety of formats.

2. Toward the end of the course, the students have the freedom to choose any particular item of interest so long as it pertains to measurement and testing that they themselves have conducted. Many students choose a past summer research experience, and there are many opportunities for students to share their newly-acquired expertise. Sometimes it is not clear what project students of nominal classroom GPA will choose. There was great delight and interest when one of our weaker academic students presented his/her interest in sound design instrumentation. Everyone in the room was captivated by the presentation of quantitative measurements and music samples that the student had collected. As I partner with this student in order to finish the programmatic requirements successfully, an opportunity of previous success exists in order to provide encouragement toward a future possibility of graduation.

Capstone Oral Exam

Science education is often associated with fear of failure, which can lead to hesitation or alteration in pursuit of further knowledge, particularly in physics (Haussler & Hoffman, 2000). Although there are complicated factors that lead to associated feelings, we see these possibilities most in our upper-level majors around the capstone oral exam. Ideally at Roanoke, this physics interview provides an opportunity for the faculty to gauge the level of attainment for a broad content range. Personally, I have experienced my own oral exam at the undergraduate and graduate levels, and from a student perspective it can seem like an interrogation. Now, having been on both sides of the table, it seems that professor's intent to help with follow-up questions~~,~~ borders on the adversarial at times. It has caused the physics group faculty to question the efficacy of the yearly routine.

While we continue to employ the oral exam in the capstone course in the major, we now invite students to begin with something they find interesting about physics or its applications. By beginning in a place where students feel comfortable, has been helpful to us to hear what they have learned during their time in the physics major. As they explain, we probe their chosen topic to find the basic physics concepts bubbling up. Asking the student, “What forces are at play here?,” or “How is energy exchanged in this system?,” provides a smooth space that disarms fear and invites curiosity where new thoughts might germinate. Rather than the content or the problem's solution taking center stage, the interaction centers on the student's aspiration and becoming as a lifetime-learner and an equal community member.

Press ('Environment')

I believe that students will gain confidence in making their own unique path when they see others assuming vulnerability and risk. For this to occur, an environment of empowerment and camaraderie must be introduced to the student. I think this must happen for the student on a personal level ("I am a contributing member of a community that supports me.") as well as a broad meta-level ("I am one following in a tradition of those before me."). In the Roanoke physics program, we attempt to address both levels in specific ways not already mentioned.

Science Outreach to the Public

Community-building is a significant component of the program already mentioned (e.g., the freshman physics colloquium). Another way that we attempt to build community is through student groups and science outreach to the public. While the public's science knowledge is commensurate with similar developed countries, scientific literacy among the general public continues to remain at an intermediate level, particularly about topics pertaining to physics, for example, climate change, nuclear energy (Pew Research Center, 2015). Science outreach not only serves the common good by helping to raise awareness at an early age, since most of the outreach is carried out with a K-8 population, but outreach also empowers the undergraduates because they are the master-apprentices. When the Roanoke physics group began a concerted science outreach effort ten years ago, most of the events were faculty-organized and led. We felt primarily as though we were burdening students to attend one more thing. Because of the fortuitous opportunity of having a series of responsible and eager undergraduate leaders, outreach has been relatively smooth in transforming the outreach program into a student-led effort. As the undergraduates succeed in this role, they are able to take on greater challenges through adding new tools to their repertoire and by communicating directly with community leaders to initiate more opportunities. One highlight was learning about a student-organized outreach completely apart from my planning or knowledge. The event took place early on a Saturday morning with several of our undergraduates, and the event included a trebuchet built by two undergraduates as a supplement to the day's activities. It was a great pleasure to receive a warm thank-you note in recognition of the undergraduate's excellent leadership and adept communication. With some of those students now graduated, the tradition is passed onto the remaining undergraduates to continue the outreach for the next year.

A second outreach experience pertains to the recent total solar eclipse. Because Roanoke was not in the path of totality, it was my intention to organize a student trip into an area where the total eclipse could be observed. Responding to an email solicitation from regional astronomy faculty, the physics group became the only official eclipse ambassadors at the entrance to a national park in the area. A little fear-stricken myself, and never having led an astronomy outreach of this magnitude, we offered the student experience to observe and to assist others as an opportunity of a lifetime. Although not as heavily attended by our majors as I had hoped, the several hundred public were certainly appreciative as they observed the hours before and after totality on the six fully-functioning telescopes that the Roanoke physics group maintained. Because the four current physics majors presented their experiences to many of their peers after their return, the news articles about our ambassadorship and the images of the event will live into the future. Experiences such as these provide bridges for new students as possibilities of what might become as a student embraces physics as a major.

History and Philosophy of Science

As a result of the external review that accompanies our regular internal programmatic review, it was clear that another formative laboratory experience would benefit our physics majors. Because our advanced laboratory at the time focused on many experiments associated with modern physics, it was a straightforward process to modify the advanced laboratory course into a modern physics laboratory. However, many questions remained about the structure of the modern laboratory and what would become of the advanced laboratory course. It was a fruitful season of higher-order critical thinking within the physics group faculty. As a result of the developments, physics majors must take a laboratory course that highlights the discipline expertise of each faculty (advanced laboratory) as well as a course that highlights the contextual science histories of famous physicists (modern physics laboratory).

It is a common mistake to view eminent scientists in history as those who just "got it" or who were destined for greatness. The linear procession of most discipline-specific textbooks weakens their accuracy of the way that science is actually conducted and/or the manner in which many discoveries actually took place. Certainly, that is the manner in which most physics textbooks portray scientists in their biographical sketches (Niaz, 2008). This includes textbooks and science history reconstructions presented in Latin America and in South America (Arriassecq & Greca, 2007; Niaz, 2011). The history and philosophy of science (HPS) provides a great humanizing infusion into the curriculum of the physics major, where students read about scientists and the process of science through a lens of iterative development rather than instantaneous inspiration. In the modern physics course at Roanoke, a significant portion of the laboratory section is spent studying the lives of the scientists who formulated the framework for the foundational physical constants that the students seek to measure. Physics majors begin to identify with the confessions of great scientists who struggled with self-confidence, personal hardship, and/or cultural biases. As undergraduates understand that great scientists were human too, students can better view themselves along the continuum of development as an aspiring-scientist.

Philosophical Foundations

While much of the curricular structures previously discussed were born out of pragmatic concerns over the low number of physics majors, or the manner in which the physics group faculty formed a response to the results of the internal program review, philosophical idealism determined the manner in which the implementation took place. Philosophy forms the foundation on which the academic program is situated. Philosophy scaffolds the new structures as they are implemented and practiced by the community. The following three philosophers all have a scientific tenor to their thoughts regarding creativity, whether or not they consider(ed) themselves practicing scientists.

Bohm's Creative Posture

David Bohm was a theoretical physicist and a philosopher of science (1917-1992), sometimes touted as one of the greatest American-born, scientific minds. Although other aspects of his scientific career may stand out, e.g., he aided in the origination of the concept of the plasma state of matter, Bohm is often remembered within the physics community for his reformulation of quantum mechanics as a "hidden variable theory" (Bohm, 1952). This novel formulation was not well-received by the physics community, and in fact it was basically ignored along with Bohm's professional career as a physicist. As a result of his search for a deeper reality undergirding all observed processes, Bohm spent a considerable amount of his later life and career constructing a framework of holism, the *Implicate Order*, which included art, science, and religion. *On Creativity* (Bohm, 2004) represents much of his summative yet distilled thought on the topic of human holism as it pertains to the development of a creative personality. Bohm's thoughts about the risk-taking (activity) required for creativity support specifically the measures introduced above.

Emphasizing what others have rightly mentioned, Bohm doesn't unambiguously correlate intelligence with a creative mind. Rather there is an imperative toward a receptive posture framed by humility, vulnerability, and risk. Of utmost importance, "a person shall not be inclined to impose her/his preconceptions on the fact as s/he sees it. Rather, s/he must be able to learn something new ...," (Bohm 2004, p. 4). Bohm (2004) further expounds, "real originality and creativity imply ... that one is ready in each case to inquire for oneself as to whether there is or is not a fundamentally significant difference between the actual fact and one's preconceived notions that opens up the possibility for creative and original work," (p. 7). It is the sensitivity and awareness to something new and different that is really important "especially when the latter [i.e., the different] seems to threaten what is familiar, precious, secure, or otherwise dear to us," (p. 6).

Closely related to the sensitivity to one's preconceived notions of what is familiar and secure, Bohm noted "that we are afraid to make mistakes," (Bohm, 2004, p. 5). Whether it be a fear of "the image of 'self'," (p. 5), "upsetting the existing state of affairs," (p. 21), or "los[ing] my comfortable and safe job," (p. 28), these can all lead the maturing and more reflective human away from new and different lines of inquiry. According to Bohm, the result of this fear is the "mechanical state of mind" which is "atrophied," "asleep," and "deadened," (pg. 20). In Bohm's view, the real detriment to creativity is the mechanical habits of thinking and being that propagate from a fear of failure. The narrowing effects of fear on our mental capacities are documented across a spectrum of real-world experiences regarding the creative mind (e.g., Catmull, 2014).

In summary, Bohm's creative keys accord with the recent findings of Tyagi, et al. (2017) that link the ability to engage in social risk-taking with increased measures of creativity. Bohm's imperative to "childlikeness" maintains an openness, a lack of fear, and a love for learning that supersede common social cues for acceptance. The educational and life experiences of undergraduate students provide serious roadblocks to the path that Bohm suggests and research supports. In hopes of creating passage, the communal emphasis of the Roanoke College physics curriculum begins with valuing equally each individual in the freshman colloquium and extends to a unique learning path through the Junior Review process. To support the development of Bohm's posture for a creative state of mind, there must be a vocabulary and a praxis that provides alternatives to the mechanicalness that oxidizes and calcifies creativity. Gilles Deleuze invites the potential for such qualities through the language of freedom and flexibility.

Deleuze's Creative Vocabulary

Gilles Deleuze (1925-1995) was a French, post-structuralist philosopher who also incorporated a significant amount of scientific terminology into his work (particularly geological and mathematical). Though Deleuze was perhaps most famous for his volume *A Thousand Plateaus*, co-authored with Felix Guattari, (Deleuze & Guattari 1987), I have also benefited from his lecture transcript "What is the Creative Act?" (Deleuze, 2004) and the conclusion to *What is Philosophy?* (Deleuze & Guattari, 1994. As testimony to the depth of thought in Deleuze, his work has impacted significantly a wide field of disciplines, including psychology, education, political theory, multiculturalism, gender studies, and film criticism. Deleuze's affinity for creativity is revealed as it was defined earlier through the "novel and useful" definition since he summarized philosophy as pertaining to the "Interesting, Remarkable" (novel) "or Important," (useful, Deleuze & Guattari, 1991/1994, p. 82). As May (2005) has rightly summarized, the importance of Deleuze's alternative vocabulary of concepts "lie not within the truth or falsity of their claims but with the vistas for thinking and living they open up for us" (p. 22). These playful yet incisive philosophical vistas encourage a personal flexibility and freedom that foster the creative activity of intellectual risk-taking.

Flexibility

Any individual attempting to answer the question "how might one live?" begins (and continues) the journey of "becoming." This one word encompasses most plainly the landscape of Deleuze's conceptual continuum, providing fertile ground for the development of a more creative mindset. In opposition to the stationary "being" of discovery, of something waiting to be found, "becoming" implies incompleteness and flexibility. Concretely, Deleuze (1962/2008) stated "there is no being beyond becoming … becoming is the affirmation of being," (p. 23-24). Although early development in Deleuze used the word "becoming" alone (May, 2003), the potency of the word is captured by Deleuze's habit of pairing the "becoming-" prefix with almost any noun (e.g., becoming-other, becoming-woman, becoming-minority, becoming-animal). The creative possibility of becoming was summarized by May (2003): "if the concepts of becoming … work, it will be because … they move us in the direction of possibilities that had before been beyond our ken," (p. 151).

Within context, many of our students come from backgrounds where they were labeled as "science and math persons" as the high school curriculum was simplistic and rote. Those static associations, "identities" in Deleuze's terms, are called into question the first time students fail a test or even can't solve a homework problem. Many, especially male students, are thrown into a quagmire of academic despair. Alternatively, some undergraduates arrive at Roanoke having always thought physics was for "other people," never having followed through with their curiosity about what might physics contain for them. In the physics group, the word "aspiring" has similar connotations to Deleuze's becoming, in the sense that we (faculty and students) are all "aspiring-physicists," "aspiring-astronomers," "aspiring-creatives," and "aspiring-adults." We have begun a journey and we have not yet arrived; we are becoming. We are aspiring to understand more deeply and thoroughly than we do currently. I use this language about myself as well as the students in order to remind them that I am a person also in process (on nomadic pilgrimage, Deleuze might say). The language of incompleteness provides enough flexibility to restore a sense of hope for future student success despite their past history with physics and/or mathematics.

Freedom

While there is perhaps no time in a student's life where more freedom is available, traditional physics curricula, and science education schema in general, maintain heavy dosages of memorization, regurgitation, and formulaic compartmentalization. As mentioned earlier, discipline-specific textbooks at the undergraduate level are presented in a linear format that doesn't accord with the historical process of science. These formats for learning physics lack creativity and imagination. Deleuze described these intellectual and physical spaces as “royal”, “striated”, and “gridded.” It is these sorts of spaces that elicit “information” in the form of “order-words” which lead to “system(s) of control.” Within these contexts, students “are told what … to believe … And not even believe, but pretend like we believe. We are not asked to believe but to behave as if we did” (Deleuze & Guattari, 1994). As one might imagine, these were not presented by Deleuze as creative environments and relationships. Against this historical and traditional backdrop, aspiring-creative educators inquire – how does an instructor organize a curriculum that does not issue order-words and information, while still engendering commitment to a particular field so that accurate ideas are produced within the unique individual?

Deleuze suggested an answer to the question of approach through his introduction of the “pass-word” concept that held out the potential for freedom. Deleuze alluded to the manner in which the word is spoken, as well as the context in which the information is provided, as some influence over whether the utterance is an order-word or a pass-word. Deleuze and Guattari (1980/1987) explain beautifully in the ending to the “Postulates of Linguistics” chapter:

> There are pass-words beneath order-words. Words that pass, words that are components of passage, whereas order-words mark stoppages or organized, stratified compositions. … it is necessary to extract one from the other—to transform the compositions of order into components of passage. (p. 110)

While undergraduate physics curricula present topics in an ordered manner, instructors also recognize the need for freedom of passage into more creative spaces. The manner in which a curriculum is passed from instructor to student, or rather the manner in which the curriculum is shared between apprentice and master, matters greatly in it becoming an order- or pass-word (Bogue, 2013).

Metaphorically, it is possible that the undergraduate physics curriculum stands as a judge, sentencing unworthiness to those who are not informed, while controlling those who “believe” or “act as if they believe” to move through the turnstiles onto the next prescripted step of graduate studies. What Physics Group faculty prefer is that the curriculum accompanies a smooth space and issues pass-words toward a sense of becoming within each individual, while also encouraging original ideas from their own freely-chosen commitment. It is my conjecture that these types of educational programs offer a recovered sense of creative potential and help produce the fruit of experimental innovation.

Galenson's Creative Types

David Galenson (1951–) is an American economist who has undertaken a study of art and creativity through an economic lens. By correlating the peak earning for an artist's work with the artist's age at the time of composition, Galenson has popularized a new dichotomy for creative personalities. Across several different genres of the traditional fine arts (painting, sculpting, music, literature), Galenson argued for a separation between conceptual and experimental innovation. Seeking “to record their perceptions” and working “tentatively by trial error,” experimental innovators “generally spend their careers pursuing a single objective” and “build their skills gradually,” (Galenson, 2010, p. 6-7). Contrastingly, conceptual innovators peak earlier and utilize art as a vehicle “to express their ideas or emotions,” (p. 7). For example, Picasso was a visionary painter whose peak-value art was created when he was in his 20's (conceptual), whereas Cezanne's most valuable artwork was created when he was in his

60's due to his methodical sense of incompleteness (experimental). Though this view of separation of creative types along the difference of personalities is somewhat contested (Accominotti, 2009), Galenson attempted to show its value by the breadth of creative innovation to which it applies.

It is not surprising that Galenson's primal correlation involved peak public recognition gained (either monetary or commendation) for the innovative art in question. Certainly the work of Galenson in delineating creative personalities fits fluidly with the physics myth that all future Nobel laureates need to establish themselves by age 21. Contrary to that myth, in Galenson's terms it is a mistake to portray all great scientists as conceptual innovators. Nobel scientists like Robert Millikan could certainly be categorized as experimental innovators, as those whose expertise and recognition emerged from a career of tinkering. While possibly students at Roanoke College will never achieve innovation on the scale of Millikan, creativity models include localized effects of novelty and usefulness. Within the context of small, liberal arts physics education at the undergraduate level, reformulating creativity frameworks to include the responsibility to facilitate, recover, and restore creative processes as it pertains to establishing Galenson's experimental innovator type. Given harsh circumstances, life experiences, or negative educational environments, the synthesis of these ideas into a small, liberal arts physics program equals one-part family (collaborative), one-part intellectual development (personal responsibility), and one-part balance of broadened possibilities (honor all trajectories).

Extensions

I have tried to show the tangible ways that the Roanoke physics program has sought to invigorate the major curriculum in order to facilitate the creative growth of students. To think that this nomadic pilgrimage of curriculum revision only impacts the students and not the instructors would be hubris. Below I explain some of the tangible ways this process and this study have impacted my own life and the manner in which I think of myself as “master-apprentice,” including my own continuing journey of “aspiring-teacher.”

Criterion for Failure

One of the difficult imperatives to fully embrace at the undergraduate level is the invitation (and possibly the requirement) to fail as a proper means of learning. Doing something new always feels risky and uncertain, and ideally we would like for our students to “fail” on the homework but not feel lost, and then learn from their mistakes in order to make amends on the exam. Brené Brown (2015) reminds us that “feeling vulnerable is at the core of difficult emotions like fear … but it's also the birthplace of … innovation, and creativity” (p. 275). Although Bohm directed us to place a love of learning before all else, it is difficult to implement that in an academic setting where grades and opinion of others still matter quite greatly. Failure is often viewed as a flaw that results in shame, rather than more likely a lack of experience which is expected. Brown (2015) comments: “Yes, maybe we lost our job or screwed up a project, but what makes that story so painful is what we tell ourselves about our own self-worth and value,” (p. 75).

Rather than just trying to lean against a fear of failure with only verbal encouragement, Allan (2013) issued a challenge to develop criteria for failure. How do we know when we've given an honest and whole-hearted attempt, one from which failing can be accepted as part of the learning process? I think the following questions properly outline a true attempt at a physics problem: Was it an honest effort?; Did I try for at least 15 continuous minutes?; Did I attempt the problem on consecutive days?; Did I look at the units of quantities and attempt to combine terms dimensionally? For future assigned problems at selected points in physics coursework, I plan to ask students to rate themselves on the “failure rubric” provided by the questions above. In a world where it is so easy to be diverted by the next thing, truly attempting something and standing a chance of failing is a worthy alternative to running away from possible defeat. Along similar lines, Smith College has recently implemented a “failure curriculum” at the liberal arts, undergraduate level (Bennett, 2017).

The Role of Expertise

Within a program of curricular alteration and substitution, and already limited by the liberal arts requirements, there is a valid question about whether or not ample coursework is offered in order to attain mastery and/or expertise. We often tell our physics students that if creativity is breaking the rules (or discovering new rules), then we must know the rules before we can break them. Both Bohm and Deleuze imply that the precursors to creativity, Bohm's “flashes of insight” and Deleuze's “ideas” arise within a deep and steady commitment to a particular field of study. In a world where academic depth and intellectual rigor are often sacrificed in the name of diversification, is the physics program at Roanoke compromising too much disciplinary expertise in order to increase participation? Is it possible that the program is hindering the growth of creativity in its majors because there is not an ample amount of expertise offered? These are valid questions that continue to offer counter balance to the current thinking and revising. In sacrificing depth in order to offer an arguably more flexible curriculum, the physics group faculty has placed an emphasis on developing and fostering a creative mindset. As increased participation necessitates a greater number of course offerings it is the hope of the physics group to offer the same curriculum qualities while also adding content depth.

Conclusions and Limitations

The physics group at Roanoke College has experienced sustained growth in the number of students enrolled in introductory classes, the number of physics majors, and the breadth of majors' trajectories after graduation. This growth coincided with the introduction of programmatic alterations that better establish community, encourage student intrinsic interests, and foster creative thinking about their futures as aspiring-scientists. All of this programmatic implementation was carried out within the context of developing experimental innovation, where students are challenged with openness as to “how might one integrate physics” and to take risks that lead along increased creative avenues. As a physics faculty, we seek to model this posture and mindset within the context of “do with me,” facilitating creative collaboration and partnership. The study is limited by its scope, having shown to be somewhat successful within a narrow timeframe and only at one particular type of college in one instance. While many of the studies reveal tendencies that are truly cross-cultural, particularly with physics education, it is somewhat expected that any alterations along similar lines to these should consider wisely cultural differences (Sharma, Ahluwalia, & Sharma 2013).

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