Research, discovery and failure

Failure is an unavoidable element of the process that leads to discovery and it should be embraced even in early education, says Deji Akinwande.

Research can be simply defined as a continual (the *re*) search for new knowledge or understanding. Discovery, that is, to find something for the first time according to the Cambridge Dictionary, is the desired outcome of research. Toddlers are arguably among the best researchers. I recall my son, Abel, spending countless periods independently fiddling around with an iPad until he discovered that a simple swipe was the gateway to entertainment, comprising a wide variety of toddler-relevant interactive apps, many of which he eventually figured out how to operate. The same goes for puzzles, Lego and a wide variety of electronic toys.

The joy of discovery can be an unquenchable driving force for learning, beneficial for all students including those from diverse backgrounds or with different learning styles and mindset characteristics, and young and old learners alike. In addition, research as a learning methodology provides all the best experiences for learning. For example, research can be a personalized learning experience while fostering collaborative teamwork and communication, it can be unstructured to varying degrees and nurture creativity and innovation, it provokes critical thinking, promotes problem-solving, improves knowledge retention, provides opportunities to deal with failure, and perhaps most importantly, research cultivates a passion for discovery.

How can failure coexist with such passion? Failure is in fact an unavoidable component of the research process and is an existential experience all too familiar to seasoned partakers, including brilliant professors, successful teachers, innovative entrepreneurs and the best leaders. In research, failure can arise from simple mistakes, flaws in the hypothesis, thought process, experimental plan or interpretation of results. My toddler tried countless times before his swipe discovery, very much like Thomas Edison's thousand (re)searches that led to the discovery of the long-lasting light bulb. There is even a non-fiction book highlighting this matter: *Failure: Why Science Is So Successful* by Stuart Firestein. I have learned to embrace failure. When I started my faculty position, I was curious to investigate graphene for electronics on flexible substrates such as plastics — a new topic at that time in 2009. I tasked one of

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my first graduate students, Jongho, with this experimental research. We both had never made a flexible device before, nor did we have any experience with plastics for electronics. Jongho conducted about 14 integration experiments, each one taking approximately a month of hard work, and all failed completely. It was a very disheartening period. With constructive feedback, Jongho showed remarkable persistence, and after about a year and a half, he was able to pull all the lessons learned together and ultimately realize working flexible graphene electronics on the fifteenth attempt. The experience with year-long failure was a defining episode for us, and he became an extremely knowledgeable and prolific engineer, authoring or co-authoring 15 original articles in the subsequent three years, leading to the attainment of his PhD degree. In this regard, failure is a great teacher in a positive setting, and is intimately interconnected with research and discovery.

In formal education at the elementary, secondary and undergraduate levels, research as a medium for learning is all but absent in science, technology, engineering and mathematics (STEM) subjects. The natural instinct for research and discovery is supplanted by passive consumption of packaged lectures where the primary incentive is achievement scores, discovery is a distant concept and failure is not an option. The noted author Arthur Koestler eloquently captured the limitations of passive lectures many decades ago (1964): “to derive pleasure from the art of discovery, as from the other arts ... the student must be made to

re-live, to some extent, the creative process. In other words, he must be induced, with proper aid and guidance, to make some of the fundamental discoveries of science by himself, to experience in his own mind some of those flashes of insight which have lightened its path ... The traditional method of confronting the student not with the problem but with the finished solution, means depriving him of all excitement, to shut off the creative impulse, [and] to reduce the adventure of mankind.”

To advance the broad area of nanotechnology for the individual and the benefit of society, the superior skill sets gained from a research-based learning paradigm are highly desirable. Encouragingly, there is a growing interest in this direction with learning paradigms such as active learning and project-based learning, which can both be considered mini-versions. I have been exploring the former in an undergraduate electronics course, and the latter in a graduate nanomaterials course, as routes towards a fuller realization of research-based learning. Both approaches have been well received by virtually every student, as evidenced by surveys. For instance, undergraduate students significantly valued the learning experience, as measured by course ratings that increased from 4.1/5.0 before active learning to 4.5/5.0 afterwards. One anonymous comment reflected the collective feedback, “I really enjoyed the discussion we had going on in class! I enjoyed listening to everyone's opinions and I also learned from them!” The challenge now is to transition to a looser structure that provides deeper opportunity for self-discovery and meaningful face time with failure, a structure all the more difficult to implement in a resource- and time-limited landscape with significant inertia. Even so, I am heartened by the growing interest in natural ideologies like research-based learning that can holistically develop the individual based on a passion for discovery and a fearless attitude towards failure. □

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