Facilitating Student Autonomy in Project-Based Learning to Foster Interest and Resilience in STEM Education and STEM Careers

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Abstract

Many students enjoy science in elementary school and middle school, until they experience a setback or disappointment in their performance in secondary STEM courses or science fairs. Educators and others, in both formal and informal settings, can foster students' continued interest and resiliency in STEM education subjects, majors and careers through student-driven project-based learning. Educators and mentors of students need to be aware of key elements of project-based learning, of realigned roles of students and teachers, and the advantages and distinctions of scientific and engineering design processes. To maximize the benefits of student autonomy in project-based learning, educators and others should also consider strategies and infrastructures that facilitate productive constructivist review and reflection, differentiated learning, confidence in presentation and publication skills, participation in science and engineering competitions, group work, and motivation for independent, lifelong learning. Collaboration among teachers in facilitating student projects can deepen student understanding and expand the context and relevance of curricula.

Introduction

AS THE CONCERN for insufficient numbers of qualified candidates for STEM (Science, Technology, Engineering and Mathematics) careers grows, science educators, STEM professionals, counselors, parents, coaches, and others can facilitate students' interest and explorations, creativity, innovation, and entrepreneurship through student-driven project-based learning. This investment in students' autonomy fosters resilience, or the ability to overcome or recover from setbacks or disappointments, in students' pursuit of STEM subjects and STEM careers.

Traditional approaches to teaching and learning can suppress and smother interest and creativity among many students who do not have resilience or support after early failures or disappointing experiences in STEM subjects. Accordingly, some students dismiss themselves from STEM subjects, majors, and careers based on experiences, and sometimes only a single experience, even before they have fully transitioned from pre-adolescent, concrete-operational thought to the capacity for abstract thinking that allows them to fully appreciate these subject areas. Regular opportunities for authentic student-led inquiry provide opportunities to renew or expand interest in technical explorations and distinctions that foster the resilience, creativity, and curiosity necessary for successful STEM careers, particularly as young people begin to define and refine their identity and self-perceptions. This resilience remains important through high school, college "weed-out" courses, and during job searches or in considering graduate programs, when so many prospective scientists and engineers switch to other academic and career paths.

Key Elements of Project-Based Learning

Project-based learning has been part of the school curriculum for nearly a century, and typically involves students in project design, problem-solving investigations, or other experiences that give students extended periods of time to work alone, or in teams, without extensive involvement of the teacher. The resulting products or presentations can be the primary means by which teachers assess students' understanding. Increasingly, project-based learning models include characteristics such as authentic content and assessment, a reduced or less didactic role for the teacher, more cooperative learning, reflective self-assessment, constructivism, developing adult communication skills, community involvement, and cognitive use of technology-based tools (Savery and Duffy, 1995). Project-based learning is also based on the constructivist principles of collaboration, personal autonomy, mentoring from older generations, reflection, active engagement in community needs, and personal or professional relevance. In his summary of research in project-based learning, John Thomas (2000) highlights five important criteria of project-based learning:

1. Project-based learning projects are central, not peripheral to the curriculum;
2. Project-based learning projects are focused on questions or problems that drive students to encounter and struggle with the central concepts and principles of a discipline;
3. Projects involve students in a constructivist investigation;
4. Projects are student-driven to some significant degree; and
5. Projects are realistic, not school-like.

Project-based learning is often distinguished from the formal, didactic, lecture settings of science classrooms, and also the controlled experiments in laboratory settings. However, it would be a mistake to believe that project-based learning should completely replace the efficiency and effectiveness of lectures and discussion in secondary science or engineering classrooms, or the need for understanding of fundamental laboratory procedures. Instead, once students have been trained in the foundations of important concepts, and laboratory techniques and procedures, they can be challenged to apply their newly acquired understandings and skills to new or more complex problems or questions.

Student-led Inquiry and the Nature of Science

The key elements of project-based learning are consistent with the National Science Education Standards (NSES), which promote an emphasis on guiding students in active and extended inquiry and a focus on student understanding through the use of knowledge, skills, and inquiry processes. The NSES also stress the importance of teachers' recognition of and response to students' individual interests, strengths, experiences, and needs (National Research Council, 1996).

Similarly, The American Association for the Advancement of Science promotes inquiry through investigation as the tool for scientific literacy in its Project 2061: Benchmarks for Scientific Literacy (2009). The Benchmarks for inquiry explicitly address the problems with common laboratory experiments designed by teachers with prescribed procedures that reflect the rigid sequence of steps of a single scientific method. These benchmarks instead promote imagination and inventiveness, collaboration, time for revisions or repetition, and sharing results for criticism. Specifically addressing student initiative and autonomy, the Benchmarks for Inquiry state the following:

> *[Students] should frame the question, design the approach, estimate the time and costs involved, calibrate the instruments, conduct trial runs, write a report, and finally, respond to criticism.*
>
> *Such investigations, whether individual or group, might take weeks or months to conduct. They might happen in and out of school time and be broken up by periods when, for technical reasons, work cannot go forward. But the total time invested will probably be no more than the sum of all those weekly one-period labs that contribute little to student understanding of scientific inquiry.*

Reinforcing Scientific Methods and Design Processes

As students choose and use scientific methods or design processes to explore their own questions or research problems, they expand their understanding of science and engineering, the importance of recognizing confounding variables, and distinguishing correlation from causation. Most approaches to science and engineering begin with identifying a question or problem. From there, scientific methods and design processes follow similar paths to different outcomes (Figure 1). The scientist will develop a hypothesis that leads to a methodology for testing the influence or relationship of a variable or variables on a specific outcome. Alternatively, engineers identify criteria or constraints for solving their problem, and then follow a design-test-redesign process to evaluate a specific model or prototype that may serve as a solution.

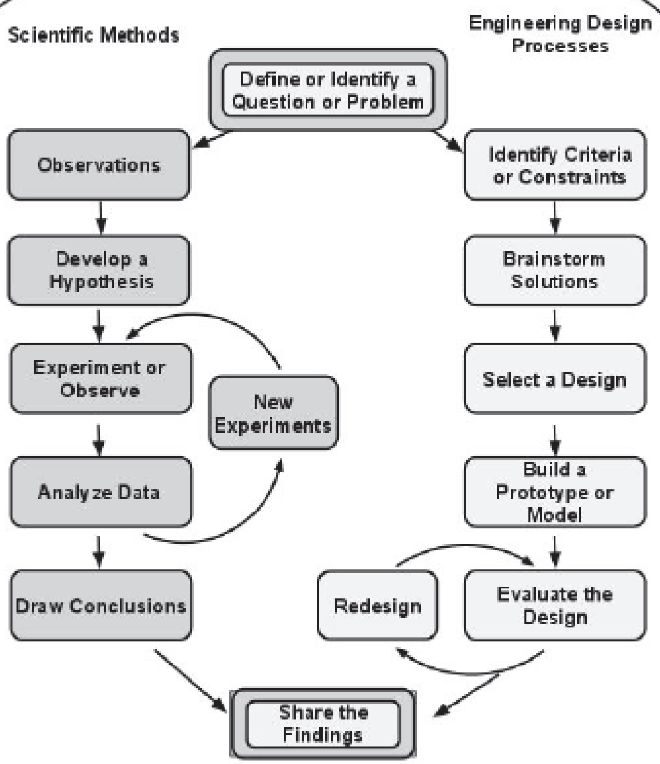

Figure 1. Examples of Scientific and Engineering Approaches in Project-Based Learning

In both science and engineering and certainly in science education and engineering education, reporting or sharing findings is an important step. Professionals rely on journal publications, poster sessions, and presentations to report and share, and these are mimicked in science and engineering fairs. Formal educators (teachers) and informal educators (parents, camp counselors, mentors, neighbors, and others) might consider other tools for sharing, as discussed later.

Teachers can reinforce skills necessary for larger research and design projects with projects of shorter duration throughout the year. These shorter projects of one to two weeks can strengthen skills in modeling and simulation, literature reviews, or developing a rationale for a larger study based on an identified community need.

Strategies for Supporting Students' Selection of Research Problems or Questions

Whether project-based learning is integrated throughout the curricula, or only quarterly or each semester, teachers must facilitate the autonomy of students in selecting, developing, and exploring their ideas. As the teacher transfers leadership to the students, the learning environment becomes more authentic, and the relevance and connections of the coursework to the students' interests and experiences is obvious. However, this creates the biggest challenges, particularly in standards-based environments where learning is measured by end-of course exams, and where teachers are accountable for student results. The teacher or mentor must continuously prompt students to tie their explorations and discoveries to the curricula, and to identify possible generalizations.

In selecting a topic, a teacher might provide some constraints for students to identify a specific topic aligned within the pace of their ongoing curriculum. For example, units within a biology course well suited for projects include biochemistry, metabolism, genetics, history of life or evolution, phylogeny and taxonomy, anatomy and physiology, and ecology. Within a unit, the teacher might provide a suggested approach, such as "Develop a model for demonstrating ____," or "Demonstrate a method for measuring ______" or "Identify and evaluate strategies for preventing _____." A teacher could provide a short timeline (two days or a weekend) for students to pick their topic, perhaps using a web-based form or a traditional sign-up sheet for others to see. After that, a teacher might provide a list of "interesting topics" to help those who did not yet identify their own. If these topics are authentic interests of the teacher, they create yet another bridge between the student and the teacher and curricula, and often students who already selected a topic may ask to switch. After another short period (perhaps only one day), the teacher can ask any remaining undecided students to pick from a list of relevant topics.

This is an important time for the teacher to transition into the role of facilitator. Throughout the selection period, the teacher can help to narrow or refine topics, suggest background research, community resources or professional mentors, or other tools, tips, or templates. Identifying a research question within a topic is an important skill for all students, and yet another opportunity for individualizing a project.

Teachers must also remain flexible, allowing for minor changes, major redirections or reorientations, or wholesale changes to topics or team participation, and to keep the students' interest and path to inquiry as a priority. Students use these moments of autonomy to define their identity, establish their uniqueness, and connect with like-minded others. Accordingly, many see these projects as a foundation or official trial or affirmation of a career interest. It is important for teachers as facilitators to avoid saying "no" or to give any hint of negativity, except when there is a concern for safety or violation of privacy (*e.g.* students desiring to study teen drug use or sexuality among their peers). Otherwise, flexibility and facilitation should be the teacher's mantra, and those who prioritize student autonomy often report that the scope of topics and products is often well beyond what they would have prescribed, or even imagined.

Strategies for Differentiation

Individualizing instruction and learning provides opportunities for more students to excel, and these successful experiences increase the possibility that connections to technical disciplines will become part of a student's personal and professional identity and lifelong learning. Teachers and others can provide differentiation in project-based learning through groupwork, tiered assignments, scaffolding, choice, and opportunities for expansion from core ideas and enduring understandings (Schlemmer and Schlemmer, 2008). Maximizing choice and interdisciplinary or cross-disciplinary connections requires additional mentoring, but provides student-derived context and relevance. Schedules, planning templates, intermediate products, and evaluation rubrics provide students with tools for formative self-assessment and checkpoints for communicating with teachers and mentors. Teachers might schedule regular one-minute interviews, where students know they'll have the teacher's undivided attention to share concerns or solicit advice.

Group Work

Some teachers avoid group work or group projects because of the difficulty in measuring individual contributions to the groups' processes or outcomes. Recognizing that project-based learning is multi-faceted, multi-disciplinary, and engages individuals at multiple levels of consciousness, the teacher can rely on group dynamics, peer coaching and mentoring, and even peer evaluation to supplant the need for artificial or unnecessary accountability structures. Instinctive group leaders can benefit greatly, even when "carrying" partners, through the deeper understanding they'll derive from teaching or guiding their peers. A participant that might be considered a cipher may not only be learning from the energy and enthusiasm of more active peers, but may also be playing a role in validating the team's direction when seemingly more-engaged peers present their rationale for routine decisions. Lab tables in many science classrooms are set to provide seating for four, but the roles and contributions of individual participants are enhanced in smaller groups, and many practitioners of project-based learning will suggest teams of one, two, or maybe three. For groups of three or four, teachers can suggest that the products of larger groups should reflect the number of group members, and can thereby comfortably assign an overall grade to the groups' products rather than individual grades to each participant.

Alternatively, teachers can guide larger groups in dividing projects into distinct but complementary roles. In an example from an AP Biology class, a group of three students designed a system for long-term monitoring and analysis of a standard blood chemistry panel and complete blood count (CBC). They shared the work of researching and explaining each blood test, but divided the rest of the work. One student determined the best way to group the more than 30 tests and identified additional blood tests that may be monitored, one determined which units were used for each test and the high and low ranges of "normal", and the third student created and formatted the spreadsheet for data collection and the creation of a template, which is now available online for others.

Monitoring and Maintaining Students' Momentum

All students, whether in middle school or graduate school, benefit from supportive monitoring. Timelines with interim products reduce the impacts of normal procrastination and also provide teachers with opportunities to help guide research, overcome obstacles, or address troubles in group dynamics. Online collaboration tools allow for teachers to monitor progress or provide comments or links to resources informally, and teachers can do this at any hour of the day. Teachers who witness the project's development also see how the final products are developed, reducing the occasion for accidental or desperate plagiarism. Online monitoring can also function as formative assessment that reduces the time required for reviewing and commenting on final products.

Sharing the Products of Students' Projects

In traditional learning environments, the products of student work have a very small audience: the teacher. And with as many as 120 or more papers, lab reports, or other work products to review, a typical teacher would need 20 hours or more per assignment, even if budgeting only 10 minutes per student for review and comments. However, if a teacher requires that the products of projects should have utility beyond the student, and requires sharing or even publication, there are many benefits. Most importantly sharing and peer review is consistent with professional scientific and engineering practices, and if done regularly in classroom environments, sharing or presenting these products becomes more comfortable and adds rigor authentically.

Knowing there will be a wider audience, students are likely to be more creative in choosing a topic or methodology, and also more likely to be more rigorous in their own self-evaluation. Second, other students can benefit from their work, whether experienced through a classroom presentation or as a newly discovered online resource. Third, if published online, students can expand or refine their products with new learning, and benefit from comments provided by others. Student volunteers can learn from categorizing or cataloguing their peers' work for publication.

If products are presented in a classroom setting, the teacher can provide praise and constructive criticism that may benefit all students' understanding, while significantly reducing the time necessary for grading the product later. Classroom presentations limited to just three minutes can provide an abstract or overview that is enough to capture the interest of engaged listeners, and short enough to build confidence in students' presentation skills without using precious classroom time.

Teachers can protect student privacy by publishing student work on a protected intranet, or publishing more publicly without last names, or without any names at all. Using increasingly available and powerful online collaboration tools, teachers can also offer suggestions for refinements, establishing a body of work that all can be proud of.

Revisiting and Revising Projects

Traditional curricula are typically progressively linear: a concept or topic is introduced and explored, perhaps with assignments and formative assessments (quizzes) leading to a summative assessment (test), and then on to the next concept. Projects, particularly those with products made available to others, allow for opportunities, and motivation to revisit past work and critique it, revise it, enhance it, or replace it. Redesign is an important part of design processes and can also be part of scientific processes in the classroom lab (Figure 1).

Science and Engineering Fairs and Festivals

Science and engineering fairs and festivals remain an important part of introducing, developing, and affirming young scientists. Unfortunately, the necessary and burdensome paperwork, and the unsatisfying outcomes for those who are not winners may discourage or dissuade more potential young scientists than are validated. However, science fair administrators partnering with non-profit organizations, trade groups, or community associations can greatly expand the number and scope of available honors awarded. Community participation has many additional benefits that further engage students, teachers, the groups' representatives, and parents in the curricula (Egenrieder, 2007).

Science and engineering fair judges often have little or no connection to secondary education, and should be trained to offer encouragement and coaching to students while reviewing their posters and demonstrations. Judges can be encouraged to bring business cards to help teachers and students expand their work or additional resources or opportunities. Some administrators of fairs and festivals for younger students (*i.e.*, middle school) also provide options for students to be *judged* by teachers only, and students thereby expect a more constructive, formative experience.

In 2011, Google launched www.google.com/sciencefair, a new, online approach to science fairs focusing on creativity and innovation, and modern approaches to sharing.

Relevance and Rigor

When project-based learning is student-driven, relevance is an inherent part of the learning experience. As the teacher functions in the less traditional facilitator and learner roles, they create a new dimension in the teacher-student relationship. The student perceives the teacher as an adult making an investment in the student's unique interests or explorations, and this new dimension in peer relationships leads to a change in the student's perceptions of teachers and themselves. This is true, of course, with any mentor or facilitator, including parents. Teachers (and science fair judges) are often concerned about parents' roles in projects, and it may be important for teachers to help parents recognize that excess involvement may lead students to believe they would have been unsuccessful without a parent's involvement. We must use our relationships with students to help them develop their own rigor in the context of their own interests.

Project Management with Technology

Online tools for communication, collaboration, publishing, scheduling, monitoring or tracking, and archiving significantly enhance the role of a project-based learning teacher or mentor (Boss and Krauss, 2007). Communications can be synchronous or asynchronous, and teams and their mentors can rely upon online document and resource storage independent of their locations (cloud computing) that facilitate collaboration. In addition to providing easy, paperless, categorized, and searchable access to helpful resources, teachers can also use technology for formal and informal assessments, collecting and organizing student products, and inexpensive (free) publishing. Blogs, wikis, and other collaborative tools allow controlled and secure collaborations among teachers in sharing and reviewing curriculum objectives, student progress and student projects; and this cooperation among teachers also expands the context of students' learning experiences.

Summary

Throughout their academic careers, students assess and reassess their aptitude for specific subjects, and their options for post-secondary studies and careers. Adults can foster students' continued interest and resiliency through project-based learning by promoting student autonomy, alignments with scientific and engineering design processes, and strategies for group work, reflection, effective presentations and publications, and the effective use of technology. As the resilient students refine their interests and expand their confidence as scientists and engineers, they are free to recognize and explore their own ideas, innovations and creative solutions to real problems. Meanwhile, they are deepening their understanding of their teachers' curricula and developing a context for lifelong learning. And when they encounter an obstacle, setback, or disappointment, they will be more likely to regroup, refocus, and renew their approach rather than switch majors or careers.

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