# Create a STEM Pipeline for Students Who Become Engineering Majors Who Become Engineers

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*ABSTRACT: This article describes the use of undergraduate college students as mentors who receive course credit for carrying out a properly structured mentor-assisted enrichment project (MAEP) with young proteges, using science, technology, engineering, and mathematics (STEM) education kits and involving professional engineers, so that youth connect "learning about" engineering concepts with "learning how" they are applied in real-world situations. This approach involves both informal and formal education to produce multiple benefits for youth and undergrads, as well as for faculty who supply undergrads as mentors, teachers who supply young proteges, and engineers who share real-world experience. Participating companies and organizations also use this project as an opportunity to recruit future hires.*

Nearly all of the initiatives and research on enhancing science, technology, engineering, and mathematics (STEM) education have focused on singular challenges, such as

- Getting youth interested in STEM subjects (mainly science and math),
- Transforming undergraduate education, and
- Using STEM professionals (engineers) as mentors for these future professionals.

Indeed, each challenge is important because there is a shortage of persons in each group:

- Not enough students are taking the right courses to become STEM majors (especially in engineering).
- There are not enough undergrads graduating in engineering.
- The United States is falling behind other nations in the number of engineers.

Typically, however, only two of these three groups are involved in a STEM initiative, such as when undergrads assist youth with robotics or rocketry in after-school programs to fulfill their own service learning requirements or when professional engineers mentor undergrads or youth to fulfill corporate social responsibility mandates. This article describes how we involved and linked all three groups to create a STEM pipeline of youth who become engineering majors and then become engineers. What we describe is based on 8 years of research and development on how to properly plan and implement mentor-assisted enrichment projects (MAEPs) with different kinds of young proteges (gifted, talented, and creative students; students who speak English as a second language; students at risk of dropping out; Native American students) at different grade levels (4–12).

## Define, Design, Align, and Deliver All Essential Components

Many STEM initiatives fail because all essential components are not identified. To rectify this, we use a collaborative planning process involving key stakeholders to define, design, align, and deliver all essential components needed to produce intended outcomes. The following are some of these essential components:

- Employing mentoring style flexibility enables mentors to provide appropriate assistance that their proteges will accept and use.
- Using a six-step mentoring process helps proteges deal with unfamiliar challenges, without telling them what to do or expecting them to figure it out for themselves.
- Creating and carrying out a mentoring action plan helps everyone prepare for meetings and attain goals, and completed plans provide evidence of what was done and learned;
- Mentor training teaches undergrads how to do these and other things so they can provide effective mentoring.
- Ongoing support and monitoring provided by a trained coordinator enhance ultimate success (no successful mentoring program "runs itself").
- A Web-based mentoring management system saves time and money (and provides a "green" solution) when hundreds of participants need to be compatibly matched, monitored, and evaluated compared with paper-based methods for these and other coordinator tasks.

Why are these and other mentoring components so essential? They are needed to satisfy all of the recommendations identified by Dubois and colleagues based on their 2011 meta-analysis of research on mentoring youth. The following were their main recommendations:

- Mentoring programs have the needed structure (expectations, guidelines, duration) to achieve intended outcomes (clearly defined purpose).
- Mentors know and fulfill expectations, roles, and responsibilities.
- Mentors are selected with backgrounds compatible with program goals.
- Mentors and proteges are matched on the basis of similar interests, complementary backgrounds, and interpersonal compatibility.
- Mentors and proteges are close in age so proteges can identify with mentors.
- Mentors shift proteges' identity (self-esteem) in a positive direction.
- Proteges have common goals for group mentoring.
- Mentors fulfill the teaching role in a systematic way.
- Mentors guide proteges' psychosocial development (social skills).
- Mentors assist proteges in achieving desired goals.
- Mentors assist proteges in achieving positive gains (e.g., handle challenges, not just discuss them).
- Mentors assist proteges in avoiding "declines" (e.g., delinquent behaviors).
- Mentors are a sounding board for proteges' ideas during discussions.
- Mentors assist proteges in engaging in extracurricular enrichment activities.
- Proteges are receptive to adult advice and perspectives.
- Mentors receive initial and follow-up training.
- Mentors have ongoing support.
- Formative evaluation is undertaken to refine the mentoring program.

Dubois et al. (2011) found that many types of mentors were used to mentor youth, most notably teachers, parents, professionals, and retirees. Sometimes these mentors volunteered their time and expertise; sometimes they were paid to do this. But Dubois et al. did not address an essential question: How can a program have quality control over any of these mentors to ensure they fulfill all of these recommendations so that intended outcomes are produced?

## Undergraduate Course Credit for Effective Mentoring

Our solution is to use undergrads as mentors and to give them course credit for providing effective mentoring. We've found that undergrads will spend more time with proteges than the assignment requires of them as they engage in worthwhile learning activities. Over an 8-year period, more than 300 of the first author's undergrads earned course credit for providing effective mentoring for more than 1,000 proteges, and none dropped out of university while doing this.

Because the age gap between mentors and proteges is small, proteges can identify with, talk candidly with, and emulate undergrads, who have achieved success dealing with the same challenges proteges are encountering. Undergrads provide the "missing link" in the pipeline between youth and professionals and a bridge that connects youth with professionals who are too busy to be full-time mentors but can plug in to a MAEP when appropriate. Undergrads are trained to use STEM education kits to maximize learning in areas like robotics, electronics, alternative energy, and rocketry. STEM education kits provide a focus for learning 21st-century skills called the 4 Cs: critical thinking and problem solving, communication, collaboration, and creativity. Mentors are trained to teach proteges how to work on a team, take turns being leader and follower, listen to each other's ideas and try ideas that seem promising of a problem solution, complete a task they start by solving the problem, and give a presentation in which they describe what they did to solve each problem and what they learned from this.

Proteges learn how to use propositional thinking (e.g., If I do this or that, what will be the consequence?) as they solve problems. This thinking skill enables proteges to make appropriate decisions in their daily interactions with others and to choose decisions that produce positive benefits versus decisions that produce negative outcomes.

## Connecting "Learning About" with "Learning How"

Undergrad mentors are trained to use the STEM education kits to help proteges *learn about* STEM topics (e.g., robotics, electronics, alternative energy). These mentors provide the right combination of didactic instruction (to teach fundamental concepts and demonstrate needed skills and procedures) and open inquiry (to engage students in discovery learning). Undergrads provide both methods for learning because research has found that both are needed to maximize learning for all students (Coleman et al. 1973). This introductory activity prepares proteges to *learn how* STEM topics are being applied in the real world by professionals, as arranged by the undergrad mentors.

Here is just one example of how undergrad mentors help young proteges connect "learning about" with "learning how": A small team of proteges wanted to learn about the relationship between architectural design and construction of buildings. Their mentor took them to view and take photos of all the major buildings in Vancouver, Canada, that Arthur Erikson had designed and then helped the proteges formulate good questions to ask him, such as "What design and construction problems had to be solved when you decided to let large trees grow through the roof of the underground library at the University of British Columbia?" "What challenges had to be resolved when you designed Simon Fraser University as a single construction to sit on top of Burnaby Mountain?"

This involvement of youth + undergrads + professionals is important because it enables young proteges to overcome their fear of science and math courses, on one hand, while exposing them to the possibilities and realities of STEM careers, on the other. Young proteges easily identify with undergrads, and they learn about best-fit careers from busy professionals so they can pursue the right career for them.

## Mentoring Action Plans

In a 1982 study, Gray found that 29 of 31 proteges in Grades 5 and 6 said their mentor-assisted enrichment project must be completed for them to view it as worthwhile ($p < 0.0000$). This motivation to complete projects was enabled by an agreed-upon mentoring action plan for each MAEP, which was created and completed by mentors and proteges, so that proteges knew from the outset what was expected:

- Come to scheduled meetings prepared to do that activity,
- Do the necessary homework,
- Complete their project, and
- Present what they did and learned.

A key to success is training undergrad mentors how to solicit input from proteges so they perceive the overall project as "theirs," even though it is based on each mentor's expertise. When activities take place on campus, this exposes youth to professors and facilities they did not know about before, enticing them to consider enrolling at these institutions. When activities take place where professionals work, this exposes proteges and mentors to real-world applications and to potential employers looking for new hires, who know how to work together on teams that produce desired outcomes.

Perhaps you've been wondering whether young proteges can create, carry out, complete, and present an enrichment program on their own after having done this with a mentor's assistance. The first author wondered the same thing and conducted research to find out; results are presented in Table 1. In a study of preference for "mentor-assisted" and "self-directed" enrichment projects involving 31 proteges in Grades 5 and 6 (Gray 1982), a survey and follow-up interviews revealed that the students had no inherent bias for doing either type of enrichment project before beginning the program (see Question 1), and many said they wanted to do a "self-directed" project after learning how to do an enrichment project with a mentor (see Question 18). Student protege responses on

**Table 1. Student Preferences for Mentor-Assisted versus Self-Directed Enrichment Projects**

| Question | Response frequency | | |
|---|---|---|---|
| | MAEP | SDEP | 2-tailed $p$ |
| 1. Which enrichment project did you most want to do *before* beginning the project? | 19 | 12 | 0.28 |
| 2. Which enrichment project did you become more interested in doing *as you worked on* the project? | 25 | 6 | 0.00 |
| 3. Which project did you most want to *complete?* | 22 | 9 | 0.03 |
| 4. Into which project did you put your *best* effort? | 22 | 9 | 0.03 |
| 5. Which project did you most want to *present* to your classmates? | 22 | 9 | 0.03 |
| 6. Which project did you do a *better job* of presenting to your classmates? | 24 | 7 | 0.00 |
| 7. Which project did you spend *more time* doing outside of school time? | 18 | 13 | 0.47 |
| 8. Which project helped you learn how to take *more responsibility* for doing an enrichment project? | 21 | 4 | 0.04 |
| 9. Which project was better *planned* so that you *finished* the whole project according to your plan? | 24 | 6 | 0.00 |
| 10. Which project was better planned *each week* so that you knew what to work on? | 24 | 6 | 0.00 |
| 11. Which project was better completed to *your* satisfaction? | 22 | 9 | 0.03 |
| 12. Which project required you to use *higher-level thinking* skills? | 20 | 11 | 0.15 |
| 13. Which project most helped you develop a *more positive self-concept?* | 22 | 9 | 0.03 |
| 14. Which project helped you learn how to *ask questions* you would later answer? | 22 | 7 | 0.01 |
| 15. Which project most required you to use the *community* as a resource? | 25 | 6 | 0.00 |
| 16. Which project most required you to use *other people* as a resource? | 25 | 5 | 0.00 |
| 17. If you were to recommend *one type* of enrichment project to a friend, which one would it be? | 27 | 4 | 0.00 |
| 18. Which type of enrichment project would you most want to do *again?* | 18 | 13 | 0.47 |
| 19. Which project do you think should be done *first?* | 24 | 7 | 0.00 |

Note. MAEP = mentor-assisted enrichment project; SDEP = self-directed enrichment project. The right column shows the probability of 31 students in Grades 5 and 6 indicating a preference for a mentor-assisted or a self-directed enrichment project based on binominal *t* tests. Missing data indicate that one or more students expressed no preference.

15 other questions clearly indicate 15 ways that mentor assistance had a significantly beneficial impact; exceptions were Question 7 (it takes time to do both kinds of enrichment project) and Question 12 (these students were already learning to use higher-level thinking skills in class).

## Multiple Benefits of the Program

Multiple benefits were produced by properly implemented mentor-assisted enrichment projects. Student proteges in Grades 4–12 benefited in multiple ways, such as the following:

- Achieve a 64% improvement in math scores and a 128% increase in technology scores while using STEM education kits to maximize learning,
- Participate in project-based, student-driven, STEM-directed activities,
- Build self-esteem,
- Develop critical-thinking and problem-solving skills,
- Engage in real-world applications of math and science,
- Acquire 21st-century skills: critical thinking and problem solving, communication, collaboration, and creativity,

- Learn how to plan and carry out a project and create and give a multimedia PowerPoint presentation of what was done and learned,
- Learn to connect "knowing about" STEM concepts with "knowing how" they are applied in real-world situations,
- Use higher-level thinking skills in each project (based on Bloom's cognitive taxonomy: knowledge, comprehension, application, analysis, synthesis, evaluation),
- Learn how to be team members (take turns leading and following) within the project group, and
- Learn how to interview and shadow STEM professionals to learn about interesting STEM occupations.

Undergraduate mentors benefitted in multiple ways, such as the following:

- Learn project management by planning, carrying out, completing, and presenting an MAEP with a group/team of proteges,
- Learn how to get proteges to see the project as "theirs" so they will carry it out and complete it,
- Learn how to make MAEP activities so engaging that proteges will complete and present "their" MAEP,
- Learn how to use STEM professionals who are too busy to be mentors to motivate interest in STEM occupations, and
- Learn how to get proteges ready to give a multimedia PowerPoint presentation of their completed MAEP.

Faculty benefit in multiple ways, such as the following:

- Learn how to structure a course assignment so all requirements will be met,
- Get significantly higher course evaluations from mentors than from other undergrads, and
- Use the multimedia PowerPoint presentations of completed MAEPs to enhance their own instruction.

Proteges' teachers benefit in multiple ways, such as the following:

- Learn how to work more cooperatively with faculty and mentors,
- Use the multimedia PowerPoint presentations of completed MAEPs to enhance their own instruction, and
- Experience increased appreciation by parents because their children benefit in multiple ways from completing an MAEP.

Schools and colleges benefit in multiple ways, such as the following:

- Learn how to work together more cooperatively on projects and associated research, and
- Because many MAEP activities occur on university or college campuses, recruit proteges to attend there.

## Conclusion

The outcomes and benefits described in this paper can only be produced intentionally by providing appropriate structures, training, and incentives based on research and development of what works and why. Informal mentoring and partially planned mentoring initiatives cannot produce such success. Only a properly planned and implemented, formalized mentoring program can ensure success because all essential components are defined, designed, aligned, and delivered.

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