Engineer's Notebook – A Design Assessment Tool

By Todd R. Kelley

The engineer must be thorough in collecting relevant information about the design problem so that he or she can accurately identify the appropriate constraints and define the design criteria.

Introduction

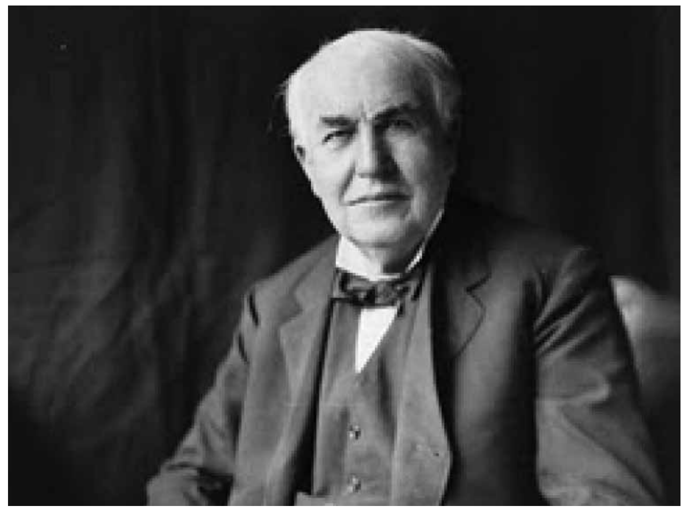
As technology education continues to consider a move toward an engineering design focus as proposed by various leaders in technology education (Dearing & Daugherty, 2004; Gattie & Wicklein, 2007; Hill, 2006; Lewis, 2005), it will be necessary to employ new pedagogical approaches. Hill (2006) provided some new perspectives regarding pedagogical approaches for technology education with an engineering design focus. One pedagogical approach suggested by Hill for technology education teachers is to require students to record their work in an engineer's notebook. Furthermore, Asunda and Hill (2007) conducted research to determine the critical features of engineering design that can be incorporated within technology education learning activities. The critical features identified by their research were complied into a rubric for the purpose of assessing engineering design projects. One critical feature identified was the use of an engineer's notebook. An engineer's notebook may not be commonly used in technology education programs, however. Kelley and Wicklein (2009) conducted a status study of engineering design within technology education. One section of this study investigated high school technology teachers' (ITEEA members) assessment practices regarding engineering design; the results revealed that the use of engineer's notebooks in technology education classes was limited. The assessment criterion survey item *"properly record design information in an engineer's notebook"* yielded a low mean of 2.01 on a five-point Likert scale. It is possible that some technology education teachers may be unaware of the key elements of an engineer's notebook or the benefits of using engineer's notebooks as a pedagogical approach and assessment strategy for engineering design instruction. Furthermore, requiring students to keep an engineer's notebook may be viewed as just another form of paperwork by students and technology teachers alike. The following article will highlight key elements of an engineer's notebook, how it is used by engineers and inventors, some rules about keeping an engineer's notebook, and an explanation as to why keeping an accurate engineer's notebook is so important to an engineer. Moreover, practical approaches to using an engineer's notebook as an effective assessment strategy will also be presented.

Engineer's Notebook: Its Purpose

The process of designing something requires diverse thinking. As people design, invent, or engineer a product or system, they must process their diverse thoughts as they work to develop their ideas, innovations, and solutions over time. Typically, engineers study design problems over a series of months and even years. Designers must consider multiple constraints within the problem and the ideal criteria of the solution before they can develop design solutions. The engineer must be thorough in collecting relevant information about the design problem so that he or she can accurately identify the appropriate constraints and define the design criteria. It is also important for the engineer to carefully record the facts gathered so that this information can be reviewed and considered later in the design process. The engineer's notebook is a pivotal tool for recording information gathered about a design problem.

Value in Documenting the "Process"

Like engineers, inventors use the design process to develop new products and systems—or innovate those that already exist—in order to satisfy our wants and needs. The process that an engineer takes to develop a design solution is very similar to the process used by an inventor. This process requires carefully recording the thoughts and observations of the inventor so that he or she can accurately assess the problem. America's most famous inventor, Thomas Edison, probably demonstrated this record-keeping process better than any other inventor in modern history. Edison is best known for inventing and innovating devices such as the lightbulb, phonograph, and motion picture camera—the successors of which we use every day. No other single person in American history has more patents than Thomas Edison, a total of over 1,000 (K.J., 2007). However, many historians and scientists today suggest that Edison's greatest contribution to our society is the records that he kept of the process he and his assistants utilized to create these important modern inventions. Historians in 1978 started gathering all of Edison's inventor notes and discovered that Edison left behind what amounted to over four million pages (McAuliffe, 1995)! These notebooks are filled with Edison's observations and insights. Some provide exact details of experiments that he and his assistants conducted while working on these important inventions. Other pages in these notebooks contained sketches, some very rough, while other sketches were very detailed and resemble finished quality design drawings. Edison realized the importance of keeping careful records to help organize his own design thinking, but also as a record for others to use. Through the inventor's notebook, Edison was able to pass on his knowledge and discoveries to his assistants as well as share these ideas with other inventors who would follow in his footsteps. Edison believed that communicating this knowledge to others was so important that he founded the *Journal of Science* in 1880, which in 1900 became the *Journal of the American Association for the Advancement of Science.*



Thomas Edison left behind over four million pages of notes.

What is an Engineer's Notebook?

An engineer's notebook is typically a hardbound book specially designed for engineers to record thoughts and report technical information for their own use and for the use of others who are working on the same design problem. The typical engineer's notebook is approximately 9"x 11½ " and contains anywhere from 100 to 150 pages (Green & Conner, 1997). The notebook is always bound and never contains loose pages, and each page is numbered consecutively. The notebook usually has a list of suggested guidelines for keeping a notebook, typically printed on one of the first pages. Often, the inside cover has a section for recording one's name, address, and other important contact information so that it can be returned to the owner if misplaced. On average, the first five pages of the notebook are dedicated to the table of contents in order to index all the pages in the notebook and their date of completion. Often, an engineer's notebook will have gridlines, either on half of the page or over the entire page. The gridlines can serve as guidelines for the recorder to write neatly or can be used as drawing guidelines for sketches. Most notebooks provide designated places at the bottom of the page for the author's signature, a witness's signature, and date of completion.

Digital Engineer's Notebooks

Emerging technologies will help teachers use electronic media platforms to generate digital engineers' notebooks. Electronic *smart pens,* document scanners, voice recorders that convert audio files to text files, and tablet PCs are just a few of the variety of tools available to help convert various forms of communication into digital document files. These technologies can help teachers save on paper and print cost. Although use of electronic engineering notebooks have been a focus of research (Gwizdka, Fox, Chignell, 1998), engineer-notebook software programs have never been fully implemented as standard engineering practice. One possible solution for technology education teachers could be to implement a digital appendix section of an engineer's notebook. Students could create digital files and burn them to a CD at the end of the design project to be included in the back of the notebook.

Why Use an Engineer's Notebook?

An engineer's notebook captures an individual's design thinking, sketches, field notes, etc., that occur as the designer seeks to study and ultimately solve the design problem. An engineer's notebook is similar to a design portfolio; a collection of examples of a student's design work, or the sequential documentation of what occurred during each phase of a design process. Technology educators have been using design portfolios in the classroom for some time. Design portfolios have been used as authentic assessment tools for design activities in elementary grades (Koch & Burghardt, 2002), and some people have even endorsed web-based portfolios for technology education (Sanders, 2000). Sanders (2000) noted that, as technology education made the shift from project method instruction to design-based instruction, technology educators sought to locate assessment methods to capture students' design thinking. Subsequently, design portfolios emerged as an ideal assessment tool. As technology education makes a shift toward engineering design and seeking to be authentic to the engineering design process, it is necessary to seek to locate authentic ways to assess students' engineering design thinking. The engineer's notebook can capture the process undertaken by students as they work through a design problem, and it remains authentic to engineering practice.

What is Recorded in an Engineer's Notebook?

Students should record any information that is related to the project or problem they are studying. The following is a list of items that may be included in an engineer's notebook (Green & Conner, 1997).

- All design thoughts
- Alternative design solutions
- Discussions you have with classmates, your teacher, and other design team members
- Problems you encounter
- Changes made to the design solutions
- Labs, experiments, test results
- Any important printouts, memos, CAD drawings (these can be taped into the notebook, see guidelines)

Engineering Design Notebook Guidelines

The following is a list of guidelines from the University of Georgia Handbook on Engineering Design. This list may need to be modified to fit the needs of your classroom.

1. On the front of the notebook enter the project title, your name, and other information needed to return the notebook to you in case it is lost.
2. Keep a table of contents at the front of the notebook.
3. All entries must be done in ink.
4. Design notebooks do not have to be neat, but they must be legible.
    a. Do not be obsessed with neatness at the expense of faithfully recording everything as it happens.
    b. Do not crowd the materials on the pages.
5. Make your entries at the time you do the work.
    a. Include all results and learned information, whether favorable or unfavorable.
    b. Include all information even if you do not fully understand it at the time of entry.
6. If you make errors, just cross them out with an X or a single line. Do not mark through anything so that it cannot be read.
7. Do not erase anything.
8. Never tear a page out of the notebook.
9. All data must be in their original form (calculations, charts, pictures, sketches on scrap paper, etc.), not after recalculation or transformation.
10. Rough drawings should be done directly in the notebook. More careful drawings, such as machine drawings or computer-generated plots, should be made and entered in the book.
11. Information on loose sheets of paper should be entered into the notebook by:
    a. Taping the loose paper to the next available blank page in the notebook
    b. Taping each corner of the loose paper
    c. Use a tape that will accept ink permanently
    d. Place your signature on the loose paper, continue across the tape and end on the design notebook page. Sign across each corner of the taped part. Date the signature.

12. Information that can be retrieved easily (such as research articles from journals) should not be entered into the notebook. Enter only the needed information and the location of the information in case you must retrieve it again.
13. Title each page of the notebook and enter the information in the Table of Contents.
14. Sign and date the notebook page at the space provided at the bottom.
15. Have your design entries witnessed, and have the witness sign and date in the space provided.
    a. The witness needs to have the technical ability to understand the entry.
    b. The work can be witnessed periodically.
16. Every page of the notebook must be numbered.
17. No pages should be skipped. This is a chronological record of your work.

University of Georgia Handbook on Engineering Design (n.d.).

Why Does an Engineer Need to Legally Record His or Her Thoughts?

Students may not understand why there are so many rules to keeping an engineer's notebook. Technology teachers need to explain that, just as there are proper procedures for all legal documents, so too are there detailed procedures for keeping an engineer's notebook. It would be helpful to explain to students that engineers solve very complicated technical problems. Sometimes an engineer designs a unique or efficient way to solve a problem and he or she may want to protect the idea from being stolen, in which case the engineer or inventor would need to apply for a patent to protect the design idea. One of the best examples in history that illustrates the value of carefully documenting a design idea in an inventor's notebook is the case of Nikola Tesla and what we know today as the radio. Many people inaccurately credit Guglielmo Marconi for inventing the radio; however, a 1943 U.S. Supreme Court ruling stripped Marconi of his 1905 patent and credited Tesla (though posthumously) with its invention because of his documents and sketches from 1893 (Kensinger, 1997). Some believe that the reason why the controversy over his patent filed in 1898 occurred was because Tesla, unlike Edison, was not meticulous in documenting his design ideas. Tesla had many patentable ideas that were never marketed because the designs were not fully tested or carefully documented (K.J. 2007). The patent process requires legal documentation of the engineer or inventor's idea, and the engineer's notebook is one of the important legal documents required when filing for a patent.

Engineers often have multiple notebooks on file for a single patented idea.

Engineer's Notebooks to Promote Reflective Thinking

How many times as educators do we ask that all-important question—what have our students learned? Hopefully, at the end of the semester or academic year there have been many forms of assessment used to determine students' capabilities; however, some of these assessments may fall short of answering that all-important question. John Dewey was a strong proponent of reflective thinking—a method or habit of mind that can help students answer this question for themselves. Asking students to provide "reflection pages" within the engineer's notebook is a great way to help students reflect upon what they are learning as they work to solve the design project or engineering problem. Rogers (2002) identifies that, often, teachers subscribe to the idea of reflective thinking for their students and further identify themselves as reflective practitioners, but often fail to fully understand Dewey's criteria for proper reflection. Rogers shares the four important criteria necessary for student reflection:

a) Reflection is a meaning-making process that moves a learner from one experience into the next with deeper understanding of its relationships with and connections to other experiences and ideas.
b) Reflection is a systematic, rigorous, disciplined way of thinking with its roots in scientific inquiry.
c) Reflection needs to happen in community, in interaction with others.
d) Reflection requires attitudes that value the personal and intellectual growth of oneself and of others. (Rogers, 2002, P. 845).

Technology educators who use an engineer's notebook in the classroom can remain true to Dewey's ideals of reflection by assigning notebook entries that can move students into higher levels of thinking and metacognition. Furthermore, the technology teacher can provide an opportunity for students to share excerpts from their "reflection pages" with the rest of the class, to the benefit of a community of reflective thinkers.

Accountability and Assessment

Cooperative learning is a great pedagogical approach, but also one that poses a major challenge for teachers, which is to determine if all members of the group are sharing the workload. An engineer's notebook is an excellent lens into the work of the group. Recently, I taught a college-level design course that required several student groups to solve an engineering problem and record their process in an engineer's notebook. On the last day of the course, the students presented their final design solutions. I was unimpressed with the final design solutions and was confused as to why the students were unsuccessful, given that their presentations each indicated that all group members shared the work load. Looking for answers, I began to review the students' notebooks, which revealed that members were missing meetings, failing to communicate with one another effectively, and taking limited ownership over their project—all indicators of poor project management, pointing to an overall lack of leadership. This experience taught me that, although I work hard to assess students' group work fairly and try to oversee all student group projects to ensure that everyone is contributing, like many other teachers, I failed to see deficiencies in cooperative learning. This revelation was made possible only by reading the entries of the students' engineer's notebooks.

Technology teachers may wonder how they will have time to read every single student's engineer's notebook. One suggestion is to create a coding process to help identify the various stages of the design process. Using the class design model, a coding process could be adopted in order to identify where each notebook entry falls in the process. For example, a common stage of any design process is *problem identification,* for which the teacher could create a code of *PI* and require students to tag the top of each notebook page that includes problem identification with a "PI." The practice of coding serves several other purposes, too. Students coding their own notebooks are required to understand the design process in order to accurately identify the various stages of their notebook entries. As students engage in this self-assessment, they are reflecting on their own thinking (metacognition), thereby becoming self-aware of things such as their own limitations, which in turn may cause them to adjust their strategies accordingly on the next iteration. The teacher can use these codes to grade the notebooks. A chart depicting frequency counts of the various stages of the design process could be created for the teacher to systematically organize the students' design strategies. For years, many technology educators have stressed that the design process was of equal importance to the end product, but they have struggled to locate an accurate method for assessing this "process" (Lewis, 1999). An engineer's notebook and a coding process might be one of the most accurate approaches to grading design projects.

Student Assessment of Technological Literacy

Some argue that *design* is the single most important category within the *Standards for Technological Literacy* (ITEA/ITEEA 2000/2002/2007) document and therefore should be considered a key area to assess for measuring students' technological literacy (Lewis, 2005). *Advancing Excellence in Technological Literacy (AETL)* (ITEA/ITEEA, 2003) provides a guide for student assessment of technological literacy. Many of the standards within this document can be addressed through assigning students to maintain an engineer's notebook. Some assessment standards are directly addressed through the notebook assignment such as:

> Standard A-4: Assessment of student learning will reflect practical contexts consistent with the nature of technology. (ITEA/ITEEA, 2003, p. 30).

Benchmarks within this standard that are specifically addressed through the implementation of an engineer's notebook are: (A) Incorporate technological problem solving; (B) Include variety in technological content and performance-based methods; (C) Facilitate critical thinking and decision making; and (E) Utilize authentic assessment (p. 31-32). Each of these benchmarks captures the essence of the process involved in maintaining an engineer's notebook. In fact, the vignette described for Standard A-4 on pages 33-35 describes the use of portfolio assessment for the assignment of a student's design task. This provided sample rubric uses eight basic stages of the technological design process as the assessment criteria; these various design stages are addressed within a well-maintained engineer's notebook. Moreover, the process of maintaining design records within an engineer's notebook is an authentic task for engineering practice, and thus a form of authentic assessment. The engineer's notebook should involve *formative* or ongoing assessment as well as *summative* or end-of-project assessment—a recommended assessment approach within the *AETL* document (ITEA/ITEEA, 2003, p.3). Formative assessment is key for implementing an engineer's notebook to inform both the teacher and the student about progress on a large design project. One of the most difficult elements of large design projects is they become unmanageable. Without formative assessment of an engineer's notebook, a student could quickly get behind in the design process and not meet his or her deadline. Weekly engineer notebook checks will help ensure that students are managing the design project properly, and the teacher will be informed if students are struggling with the design activity.

Closing

Hopefully, this article has provided the reader with new insights into the history and function of engineer's notebooks, as well as the merits to using them in the technology education classroom. It is the author's hope that this article has also provided teachers with practical approaches to using an engineer's notebook as part of an effective strategy to assess individual and group work. In the introduction of this article, it was mentioned that an engineer's notebook may be viewed by students and teachers alike as just another form of paperwork—and the author has made observations in pre-engineering classrooms where the notebooks were required in the curriculum, but too many requirements and an overemphasis on the process of keeping a notebook resulted in busywork for students. However, implemented correctly, students and teachers will benefit from the use of engineer's notebooks for the same reasons they have been utilized and valued throughout the history of American innovation.

References

Asunda, P. A. & Hill, R. B. (2007). Critical features of engineering design in technology education. *Journal of Industrial Teacher Education, 44*(1), 25-48.

Dearing, B. M. & Daugherty, M. K. (2004). Delivering engineering content in technology education. *The Technology Teacher, 64*(3), 8-11.

Gattie, D. K. & Wicklein, R. C. (2007). Curricular value and instructional needs for infusing engineering design into K-12 technology education. *Journal of Technology Education, 19*(1), 6-18.

Green, D. G. & Conner, D. A. (1997). The Engineering Notebook. Retrieved from http://www-ece.eng.uab.edu/Dgreen/notebook.html

Gwizdka, J., Fox, M., & Chignell, M. (1998). Electronic engineering notebooks: A study in structuring design meeting notes. Proceeding of Enabling Technologies: Infrastructure for Collaborative Enterprises. Stanford, CA.

Hill, R. B. (2006). New perspectives: Technology teacher education and engineering design. *Journal of Industrial Teacher Education, 43*(3), 45-63.

International Technology Education Association (ITEA/ITEEA). (2000/2002/2007). *Standards for technological literacy: Content for the study of technology.* Reston, VA: Author.

International Technology Education Association (ITEA/ITEEA). (2003). *Advancing excellence in technological literacy: Student assessment, professional development, and program standards.* Reston, VA: Author.

Jablokow, K. (2007). Different approaches, Great results. *Mechanical Engineering, 129*(2), 32.

Kelley, T. & Wicklein, R. C. (2009). Examination of assessment practice for engineering design projects in secondary technology education. *Journal of Industrial Teacher Education, 46*(2), 6-25.

Kensinger, S. (1997). Reengineering engineering: Reinventing inventing. *Computer-Aided Engineering, 16*(11) 60-62.

Koch, J. & Burghardt, D. (2002). Design technology in the elementary school—A study of teacher action research. *Journal of Technology Education, 13*(2), 21-33.

McAuliffe, K. (1995). The undiscovered world of Thomas Edison. *The Atlantic, 276*(6), 80-89.

Lewis, T. (2005). Coming to terms with engineering design as content. *Journal of Technology Education, 16*(2), 37-54.

Lewis, T. (1999). Content or process approaches to technology education curriculum: Does it matter come Monday morning? *Journal of Technology Education 11*(1), 45-59.

Rodgers, C. R. (2002). Defining reflection: Another look at John Dewey and reflective thinking. *Teachers College Record, 104*(4), 842-866.

Sanders, M. (2000). Web-based portfolios for technology education: A personal case study. *The Journal of Technology Studies, 26*(1).

University of Georgia *(n.d.). handbook on engineering design.*

Todd R. Kelley *is an assistant professor in the college of Technology (and P-12 STEM Researcher) at Purdue University, West Lafayette, IN. He can be reached via email at trkelley@purdue.edu*

This is a refereed article.