Developing More Robust Problem Solvers through Diversity of Course Experiences

Elif E. Miskioğlu
Department of Chemical Engineering
Bucknell University
Lewisburg, PA
elif.miskioglu@bucknell.edu

***Abstract*— There is little argument that problem-solving is the crux of engineering. As engineering educators, we pride ourselves not only in developing technical experts, but in developing diverse thinkers and innovators ready to tackle the challenges of tomorrow. Arguably, the most critical point in problem-solving at this level is the ability to interact with a wide variety of information. It allows for understanding goals, identifying scope, and setting assumptions. Thus, we believe that a greater exposure to different avenues of working with information can lead to more robust problem-solving skills, and should be considered in our coursework development. It is essential that our students leave our programs with not only high degrees of content knowledge, but also the comfort and ability to engage with information. We give great credence to the diversity and difficulty of unforeseen future societal challenges, yet our curricula does not fully represent this. Realistic problems are often open-ended, ambiguous, and/or have multiple solutions, making them difficult to incorporate into 15-week courses. However, there may be other ways to promote diversity of problem-solving skills through avenues better suited for our current academic system. We have developed a method of categorizing problems based on learning style biases—learning styles exploited in the problem solution or presentation—that allows instructors to check how they are asking students to engage with information to solve problems. Our previous work suggests that most instructors favor highly homogeneous problem types, and that certain styles are neglected in course experiences. While learning styles remain a controversial topic in education, we believe this application is a perfect example of their potential use for positive impact in engineering education. Learning styles define how individuals interact with information—how they receive, perceive, process, and understand information. This makes learning styles a well-suited tool for evaluating and improving upon our current practices and the extent to which we task our students with solving diverse problems. We have developed a set of criteria, based on the Felder-Silverman model of learning styles, which allows instructors to quickly evaluate presentation and solution biases in their coursework (problems, projects, etc.) and easily assess whether they are providing students diverse opportunities to engage with information. We believe that the more learning styles students are exposed to through problem presentation and solution, the more robust their problem-solving skills will be, as they will readily be able to receive, perceive, process, and understand information presented or utilized in a variety of ways. This methodology is less concerned with students' own preferences, but rather, focuses on creating a "balanced" course experience with respect to learning styles (irrespective of student preferences). The criteria can be used both for assessment of existing problems, and development of new problems. We believe that adoption of methods such as these to assess and reevaluate our curricula can further propel us along the path of developing the engineers of the future.**

Keywords*— *developing problem solvers, evaluating instructional approaches, teaching tools

I. PREPARING FUTURE ENGINEERS

As society advances, so do the problems we face. A common saying in academia is that we are preparing our students to solve problems that do not yet exist—problems that are beyond the scope of what we can foresee. As globalization and technological development occur at what seems to be an ever-increasing rate, the rate at which we are confronted by heretofore unheard of problems will follow suit. Thus, while the structure and role of the university is questioned in modern society, the importance of education, and the development of technical experts (e.g., engineers), has never been greater.

An undergraduate degree in engineering carries many expectations. It represents not just a breadth and depth of discipline-specific technical knowledge, but also a deep ability to solve societal problems. The ABET student outcomes [1] reflect this by including everything from technical skills (e.g., outcomes (a) and (k)) to design of experiments (b), recognizing broader impacts (h), and professional skills (e.g., (g) and (d)).

ABET outcome (e) specifically highlights problem solving skills that engineers must possess—"an ability to identify, formulate, and solve engineering problems." This outcome may be considered to be most at the heart of the engineering discipline, as the term engineer and problem solver are often used interchangeably. Thus, it may be said that problem solving is at the crux of the engineering discipline, and it follows that developing the problem solving skills of our students (i.e., developing problem solvers) should be the focus of our engineering curricula. Recognizing the diversity and difficulty of unforeseen future societal challenges, we must not only develop capable problem solvers, but versatile problem solvers ready to tackle the variety of situations they may face.

While project-based courses such as senior design are concerted attempts to provide students with a more ‘real world’ problem solving experience drawing on their technical knowledge, there is an opportunity to build subtle experiences into the curricula that broaden our students’ ability to problem solve. The approach recommended here draws on learning styles theory as a lens through which to view and expand our current curricular practices and its potential for developing problem solving skills in our students.

II. Learning Styles in Education

The application of learning styles in education is a highly contested topic [2-12]. Much of this, however, stems from attempts to apply learning styles theories in the improper context.

Learning styles are a tool for identifying how an individual interacts with information. They describe how information is received, perceived, processed, and understood. We do not believe that they are absolutes, but rather ways of categorizing different modes of engaging information.

The ability to solve problems relies heavily on the ability to manage information in a variety of forms. These forms may be described by the temperaments of a learning styles theory. Thus, it could be argued that students who are able to comfortably maneuver through all learning styles may be the strongest problem solvers. It is our responsibility as educators to provide opportunities for students to engage in activities that promote experiences across all learning styles throughout their undergraduate careers.

There are many popular learning styles models used in education. We favor the Felder-Silverman model [4] (discussed in Section IV) in our learning styles focused approach to curricular design because it provides a multidimensional categorization of learning styles, better capturing the subtleties of how information may be exchanged and processed. Additionally, it was developed specifically with applications to engineering education in mind.

III. Learning Style Biases in Curriculum

Throughout this work, the term learning style bias will be used to describe the learning styles exploited by a specific task. This may be the learning style(s) represented in the presentation of a problem, required to solve the problem, etc. This work is based on the principle that course tasks (lectures, activities, problems) may be characterized by learning style biases as both an evaluative tool for current courses, and a development tool for course improvement.

Previous work suggests faculty are biased towards engaging certain learning styles [13]. While it may be appropriate for a single course in the curriculum to demonstrate specific learning styles biases, if all courses demonstrate single biases we limit our students’ exposure and opportunity to master the material using information presented in unfamiliar ways. By engaging more learning styles in our curricula we may better ensure that we are developing exceptional, diverse, problem solvers.

We believe that learning styles theory, when properly applied, may provide us with a tool to both evaluate our existing curricula and allow instructors to improve their course design by exposing students to a variety of learning styles. This approach is not concerned with the students’ own preferred learning styles, but rather, based on the theory that all students should diversify their learning styles experiences.

Course experiences (homework, exams, in-class and out-of-class activities) often have a natural learning styles bias in either the task presentation, process of completion, or solution. It is in these experiences that we can look to identify (1) what learning styles are we exposing our students to? and (2) how can we (as instructors) modify the course experiences to expose students to a greater variety of learning styles?

Our previous work (applying an early version of the criterion table presented in this work) suggests that faculty unconsciously demonstrate learning style biases in the problems they provide on exams, and that these are highly similar across faculty teaching the same course [13]. These biases are likely reflected throughout the course, and a deeper investigation of what each dimension in the Felder-Silverman model represents allows us to identify how that learning style may manifest in our courses and develop criterion by which to recognize each bias.

IV. Felder-Silverman Learning Styles Model and Identifying Biases

This section provides a detailed description of the Felder-Silverman learning style preferences organized by dimension [4], and highlights how these preferences naturally appear in our courses.

A. Active vs. Reflective

The active/reflective dimension describes how individuals process information. Much as the names suggest, active learners favor ‘doing something’ with new material, e.g., doing an example problem or a lab experiment, whereas reflective learners prefer to internally ponder new material.

Engineering students are characterized as predominantly active learners [5]. Activities that engage active learning include group work, problem-based learning, and experiments. Activities that engage reflective learning include: individual work, traditional lecture, and think-pair-share.

B. Sensing vs. Intuitive

The Felder-Silverman sensing/intuitive dimension is much like the Myers Briggs Personality Type Indicator dimension of the same name. Sensors are prefer facts, numbers, and details. Intuitors are characterized by preference towards the theoretical and abstract.

Previous work suggests that undergraduate engineers are not only more often sensors [5, 13], but also are more comfortable working in the sensing dimension (from self-reports on perceptions of tasks). Similarly, our previous work has identified intuitive problems as a weakness among engineering students coupled with a preference among faculty for testing students on sensing problems [13].

Sensing appears in coursework through problems and tasks focused on numerical information. Example problems with numbers, for example, is a clear sensing-oriented activity. Intuitive activities focus more on theories and abstract concepts. Interpretation of a numerical answer that requires theoretical/conceptual understanding, for example, is an intuitive activity.

C. Visual vs. Verbal

The visual/verbal dimension, as the name implies, refers to how information is received. Visual learners prefer visual representations of information—cartoons, graphs, etc. Verbal learners prefer words, written or oral. The ability to receive, and process, information in both forms is essential to success as an engineer.

Much of undergraduate engineering curricula emphasizes the need to use the visual learning style. All engineering students are taught free body diagrams in their physics classes, and similarly encouraged to continue creating visual representations of problems in their specific discipline. In many cases this is an explicit requirement of introductory courses, where students are taken through a stepwise process that involves developing a diagram. However, in later courses, students may no longer be given such explicit directions. We have seen that in these cases, students may or may not choose to create a visual representation of the problem, and verbal learners are less likely to then their visual counterparts [13].

Engineering students are characterized as largely visual learners [5, 13], but fluency in both 'languages' is essential. Students must be comfortable gathering the needed information from text or conversation, as well as interpreting diagrams.

As may be deduced, visual activities involves anything where students are exposed to visual representations of information, or required to produce one. Verbal activities, on the other hand, require interpreting written or oral information, or producing written or oral explanations.

D. Sequential vs. Global

The sequential/global dimension describes individual preference with regards to understanding information. Sequential learners, as the name suggests, prefer a stepwise, linear understanding process. Global learners, on the other hand, are described as understanding in "fits and starts" and not necessarily needing a linear sequence to get to the final conclusion.

As sequential learners are more common among engineering students [5, 13], many courses and problems are set up to promote sequential understanding. The nature of education has a great deal of linear sequencing inherently built in—from the progression of core courses to the approach to introducing new concepts within a course. Previous work has shown that students are much more comfortable and successful with sequential tasks [13], but arguably much of real-world engineering problems require a more global approach. Thus, creating more global learning opportunities for our students is an important factor in developing more robust engineers.

Sequential activities are present in our courses anytime students are asked to follow a linear process to achieve the goal given (most often, solving a homework or exam problem). Global activities, on the contrary, are less structured, and require students to explore and determine the steps necessary to complete the activity themselves. They usually rely on students developing solid assumptions to be able to proceed. This is often well-represented in class projects such as those completed in senior design.

V. Applying Learning Styles Theory to Course Design

With the multitude of demands on academic professionals, time is a great barrier to implementing new course interventions. The ideal intervention is high impact and low cost (in both time and money). Provided here is an easy-to-use tool for instructors interested in broadening the scope of their teaching methods (as well as evaluating the scope of their current teaching methods) in an effort to better prepare our students for the diversity of real-world problem solving they will experience upon matriculation from the university.

Table 1 (following page) is a proposed criterion table for evaluating learning style bias in engineering course activities

Table 1. Criterion table for identifying learning style biases in course activities. The shading is used to group adjacent rows that belong to the same dimension from the Felder-Silverman model.

Dimension Preference	Criteria
Active	• Problem presentation or solution is highly representative of a problem the students have previously solved (similar to previous problem) • Problem (solution) introduces new material through fieldwork or experimental doing
Reflective	• Problem presentation or solution is representative of ideas covered but not practiced in class (e.g., a law or theorem that was presented but no homework regarding it was assigned) • Problem solution requires concerted thought, without opportunity to experimentally try the process in a question
Sensing	• Problem presentation strongly focuses on providing numbers and implies that the solution will require numerical calculations (e.g., "plug-and-chug") • Problem solution focuses on numerical solution
Intuitive	• Problem presentation focuses on concepts and theories (e.g. introduces a new formula, concept, or theory in the problem statement or directly refers to application of a theory) • Problem solution requires conceptual and theoretical understanding rather than numerical understanding
Visual	• Problem presentation uses visuals (e.g. table, image, graph, chart, but not a straight data table), with few/no text descriptions • Problem solution requires interpreting visually presented data (e.g., graphs, charts) • Problem solution requires creating visual depiction (e.g., process diagram)
Verbal	• Problem presentation uses words without using any of the visuals described above • Problem solution requires extensive written explanation (often paired with intuitive)
Sequential	• Problem presentation suggests one part of the problem leads into the next in a step-by-step (i.e., sequential) fashion • Problem solution follows a distinct sequence of steps/calculations • Problem solution assumptions are provided and/or otherwise made obvious by problem statement • All information needed for the problem solution is provided
Global	• Problem is presented directly, where information is provided and the final question is asked without any indication or hints of possible steps needed to get to the solution • Problem solution does not follow a distinct sequence of steps/calculations, but rather tests overall understanding of how to obtain the final answer • Problem solution requires development of assumptions • Some information needed for the problem may need to be looked up

using the Felder-Silverman learning styles model. It is important to note that not all activities may demonstrate an explicit learning style bias, and many will engage more than one learning style. These criterion are developed from the interpretation of the Felder-Silverman model of learning styles presented in the previous section, and are useful for both evaluating existing learning styles biases and aiding design of courses seeking a more balanced learning styles approach.

While it may not be feasible to completely overhaul existing courses, there are several low-cost interventions that may be included in existing courses to expand the learning styles students are exposed to. Considering each dimension and subsequent preference separately, some example interventions include:

1. Active/reflective: expand upon think-pair-share model to develop both active and reflective processing
2. Sensing/intuitive: "one-minute" theoretical concept questions at the end of class to reinforce intuitive perception
3. Visual/verbal: practice "translating" information from one context to another, e.g., reading students a problem and not drawing anything on the board to strengthen student ability to receive information in either form
4. Sequential/global: developing assumptions or open-ended solutions to enhance students' global understanding

There are, of course, countless ways to engage each learning style preference throughout a course. What is most appropriate will depend on course learning objectives and available resources. Table 2 (next page) provides an example of how one can use the constructed criterion table. Here a simple mass balance problem (chemical engineering) can be modified to exploit different learning styles in presentation or solution. The original problem statement may be altered to provide more, less, or different information as is appropriate for the desired learning outcomes.

VI. Continuing to Adapt

The learning styles based approach to broadening curricular outcomes and developing our students into more robust problem solvers is just one method that can help us continue to adapt to the ever-changing demands of our field. It is both easy-to-use and easy-to-implement, making it an appealing tool for busy educators at all levels.

This approach can be used by a single instructor interested in evaluating and possibly redesigning a course, or by a curriculum committee in assessing an entire program. Especially in early courses where students are building foundational knowledge it may not be appropriate to heavily incorporate styles such as intuitive or global. If so, more senior classes should focus more heavily on those styles, to ensure that students receive a balanced curriculum overall.

The field of engineering is far from stagnant, and the demands on each successive generation of engineers will be different from the previous one(s). As society continues to advance at a rapid pace, and "the future is now" becomes increasingly evident, the demands on engineers will evolve to meet societal needs. We readily accept that the problems our students will be faced with in their careers will be highly complex, and many beyond the scope of what we can predict. It is our responsibility as educators to prepare our students in the best way possible for these challenges. Incorporating true 'real world' experiences into the current academic system is difficult, however, there are more easily adoptable methods to achieve improvements in our curricula. A learning-styles based approach to diversifying course activities is one such method. By developing a list of criterion to easily identify learning styles biases in course activities, this approach makes it easy to both assess the state of current courses and develop new materials in an effort to create more "balanced" curricular experiences. The more learning styles our students are exposed to (and gain mastery of) in their undergraduate curriculum, the more prepared they will be to manage the information needed to solve the problems of tomorrow.

Table 2. Example of problem statement and how the criterion table can be applied to adjust the presentation and solution to the problem to engage different learning styles biases. The shading is used to group adjacent rows that belong to the same dimension from the Felder-Silverman model.

<table>
<tr><td colspan="3">Original Problem Statement: Rice krispies treats are made of rice krispies, butter, and marshmallow. The final product is 9% fat, 36% sugar, 41% other carbs, and 14% “other” by mass. How much of each ingredient (rice krispies, butter, and marshmallows) is needed to produce a 10,314 lb treat (the world record set in 2010)? Nutritional information of rice krispies, butter, and marshmallows provides compositions for each:
• Rice krispies are 11% sugar, 79% other carbs, and 10% “other” by mass
• Butter is 81% fat and 19% “other” by mass
• Marshmallows are 58% sugar, 24 % other carbs, and 18% “other” by mass</td></tr>
<tr><th>Dimension Preference</th><th>Presentation</th><th>Solution</th></tr>
<tr><td>Active</td><td>Do not provide extra background information on mass balances, but rather use a problem such as this to introduce the concept.</td><td>Have students work in teams to solve the problem, and check in with teams periodically to reinforce concepts they’ve discovered along the way.</td></tr>
<tr><td>Reflective</td><td>Introduce concept of mass balances first, then provide students problem (preferably as homework).</td><td>Have students complete problem individually, tie problem to the concepts they have just learned.</td></tr>
<tr><td>Sensing</td><td>Use numerical values in the problem statement.</td><td>Have students provide numerical solution.</td></tr>
<tr><td>Intuitive</td><td>Replace numerical values with variables.
Ask students to comment on heuristic observations regarding problem—what would change, for example, if certain parameters changed?</td><td>Have students set-up a generic (non-numeric) solution for problem. Ask them to identify information that they would need to look up, and what they have solved for.
Have students comment on the concepts that the problem demonstrates (conservation of mass).</td></tr>
<tr><td>Visual</td><td>Present problem through a process flow diagram.</td><td>Have students create process flow diagram for problem.</td></tr>
<tr><td>Verbal</td><td>Use written or orally delivered problem statement.</td><td>Have students submit a written response outlining the results of their solution, or give a presentation.</td></tr>
<tr><td>Sequential</td><td>Give students a step-wise solution method (you can even start with using nutrition labels to find mass % of components in each ingredient).</td><td>Have students develop a step-wise solution method, and present their work in a linear, organized fashion.</td></tr>
<tr><td>Global</td><td>Do not provide any scaffolding to students with problem statement. Provide less information than is given above, and force students to make assumptions to move forward.</td><td>Provide less information than is given above, and force students to make assumptions to move forward.</td></tr>
</table>

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REFERENCES

[1] ABET, "Criteria For Accrediting Engineering Programs," 2014.

[2] F. Coffield, D. Moseley, E. Hall, and K. Ecclestone, "Learning styles and pedagogy in post-16 learning: A systematic and critical review," 2004.

[3] F. Coffield, D. Moseley, E. Hall, and K. Ecclestone, "Should we be using learning styles?: What research has to say to practice," 2004.

[4] R. M. Felder and L. K. Silverman, "Learning and Teaching Styles in Engineering Education," *Engr Education,* vol. 78, pp. 674-681, 1988.

[5] R. M. Felder and J. Spurlin, "Applications, Reliability and Validity of the Index of Learning Styles," *Int. J. Engng Ed,* vol. 21, pp. 103-112, 2005.

[6] D. A. Kolb, "Learning styles and disciplinary differences," *The modern American college,* pp. 232-255, 1981.

[7] E. Martin and P. Paredes, "Using Learning Styles for Dynamic Group Formation in Adaptive Collaborative Hypermedia Systems.," in *First International Workshop on Adaptive Hypermedia and Collaborative Web-based Systems.*, Munich, Germany, 2004, pp. 188-198.

[8] S. M. Montgomery and L. N. Groat, "Student learning styles and their implications for teaching," *CRLT Occasional papers,* vol. 10, pp. 1-8, 1998.

[9] H. Pashler, M. McDaniel, D. Rohrer, and R. Bjork, "Learning Styles: Concepts and Evidence," *Psychological Science in the Public Interest,* vol. 9, pp. 105-119, December 1, 2008 2008.

[10] J. T. E. Richardson, "Approaches to studying, conceptions of learning and learning styles in higher education," *Learning and Individual Differences,* vol. 21, pp. 288-293, 6// 2011.

[11] D. Rohrer and H. Pashler, "Learning styles: where's the evidence?," *Medical Education,* vol. 46, pp. 634-635, 2012.

[12] R. R. Sims and S. J. Sims, *Importance of Learning Styles, The: Understanding the Implications for Learning, Course Design, and Education: Understanding the Implications for Learning, Course Design, and Education*: ABC-CLIO, 1995.

[13] E. E. Miskioğlu, "Learning in Style: Investigation of Factors Impacting Student Success in Chemical Engineering at Individual and Team-Levels with a Focus on Student Learning Styles," The Ohio State University, 2015.