Session 2132

Learning to Think Critically to Solve Engineering Problems: Revisiting John Dewey's ideas for evaluating the engineering education

Mani Mina, Iraj Omidvar, and Kathleen Knott
Iowa State University

1. Introduction: Engineering education

1.1 Our Goals: How Well we Teach Problem Solving to Engineering Students

In this paper we would like to take a critical look at the process of engineering education. In particular, because most engineering programs aim, among other goals, to teach engineering students to become problem solvers[1,2], we will examine the skills that engineering problem solvers have and how well we are in teaching "problem solving" skills.

1.2 Our Findings Are Applicable to Other Disciplines

We have broad experience in working with students from different backgrounds. Although our experience is mainly with electrical and computer engineering students, we believe that our observations, explanations, questions, and concerns will be of relevance to other engineering disciplines.

1.3 Engineering Programs: Description, Objectives, and Requirements

In the typical electrical engineering program with which we are familiar, students are required to take a series of basic and specialized courses. The multidimensional requirements of the program are designed to provide the opportunity to the students to become a competent and conscientious engineer and citizen.

In specialized courses, students are taught an information base (Maxwell equations, Laplace transform, etc.) considered useful in solving engineering problems. In addition, students are required to solve certain types of problems, become familiar with certain types of examples, take tests, and complete projects in order to familiarize themselves with the fundamentals of the field: the methodology usually used by electrical engineers as well as the tools and processes considered helpful to students for learning good engineering designs and practices. As is the case with all engineering programs, the goal of our electrical engineering program is to train well-rounded electrical engineers who are competent in their field, responsible in their actions, creative in their thinking, ethical in their lives, and dependable members in the profession as well as in society. Those of us who have been involved with curriculum committees know the difficulties associated with training well-rounded and creative engineers within the four-to-five year timeframe of an undergraduate-education program. Thus, in addition to general, introductory, and specialized classes in mathematics, physics, and engineering, students are required to take courses in diversity, social science, and general education. The goals of these classes—like those of the specialized and design courses—are to teach students to become adept at practicing and using systematic thinking processes (engineering problem solving).

2.. Engineering Problem Solvers

2.1 Why Engineering Programs Teach Problem Solving Skills

The goal of engineering programs is to educate competent engineers. Because the working environments and experiences of engineering students will differ greatly after graduation, engineering programs aspire to teach a set of skills that will be of value in different working environments. Regardless of their positions, all graduates can expect to be faced with new problems they must solve. Thus, engineering programs invest much time and effort creating engineering problem solvers.

2.2 What Engineering Programs Mean by Educating Problem Solvers

In our experience, engineering problem solvers are considered to be individuals who find best-fit solutions, given a certain (limited) number of criteria (specifications To be true problem solvers, students need to have creative thinking processes that are acquired through good training in analysis, hours of practice, exposure to good and creative solutions, and student flexibility in approaches to the discipline. To help create such problem solvers, we teach our students to think within the framework of the engineering discipline by presenting to them engineering methodologies and concepts. Problem solving is usually described to have five steps, which are taught in the freshman engineering programs: identify the problem, hypothesize a solution, test the solution, analyze findings, and present the answer.

3. Learning Conditions for Students

Engineering students are faced with increasingly more demanding programs that require them not only to take more classes and fulfill more curricular requirements but, within individual classes, to study a great many technical and non-technical (social, ethical, managerial, etc.) topics. Moreover, many students work long hours while in school. Consequently, many students go through programs without detailed exposure to the knowledge and without thorough practice of the skills intended for them. Many students merely try to do whatever is required to pass classes.

3.1 Problem: Students Learn to Be Blind Followers

To be trained as effective engineers and technical problem solvers, students need to know many engineering fundamental and be able to engage their knowledge base with problems in order to solve them in a timely way and at a reasonable cost. This is a process that demands hard work and can put tremendous stresses on students as well as educators.

3.2 The issue

Many engineering educators know that students are under pressure not to attend to some details of what it takes to be well-rounded engineers. Moreover, the teaching process is focused on obtaining engineering solutions. The answer is the primary goal, not the quality and depth of thought. In the final analysis the problem solving task is seen as finding solutions that agree with the specifications. Of course, most students have the best of intentions, but academic and lifestyle pressures force students to follow the methodologies, ideas, and examples presented in laboratories and lectures.

Most students are perfectly capable of becoming engineering problem solvers, but, in our experience, a combination of over-crowded classes, over-whelming range of topics taught, and oversubscribed students (overworked students who take too many classes per semester) create an

environment in which students have no time to invest any more time and effort in their studies than what is absolutely necessary to receive passing grades (that is, to "psych" the instructor and the program). The tendency to follow disciplinary practices blindly instead of acting as dynamic, competent, and creative engineering problem solvers that engineering programs aim at producing create severe problems down the road for all stakeholders in engineering education.
To understand the problem more clearly, here we point out some of the issues of concern.

3.2.1 From the Students' Perspective

Students may not suffer immediate, debilitating professional consequences if they merely do the required work and receive passing grades. As long as demand for engineers in the market is high, employers may accept blind imitators and invest the time and resources to re-educate them. But when the market is stagnant or when the industry has to undergo major adaptations (for example, to newly developed technologies), blind imitators, that is, graduates who have successfully learned their knowledge base but were not equipped with the necessary skill to be life-long learners will be at a great disadvantage.

3.2.2 From the Instructors' Perspective

From the instructors' perspective, this problem poses serious and rather complicated challenges. On the one hand, we try our best to teach students to be creative thinkers, inquirers of knowledge, and life-long learners. But on the other hand, the problem raises the question of what, if anything, instructors can do to solve the problem. If despite our best efforts, many engineering students become blind imitators, where lies the problem? Is the problem causes by the structure and content of the curriculum? By the teaching methodologies of instructors? By external socio-economic forces? Etc.

These questions can help instructors find a way out of the problem. But because most engineering instructors do not receive specific training in pedagogy and (the very many) other aspects of education, the raising of such questions can seem irritating. Nevertheless, we believe that unless we constantly review our work with students and change our teaching styles dynamically, we may fail in our mission of educating competent engineers.

The tendency among engineering students to imitate also constitutes a problem for graduate programs. For example, in electrical engineering and related fields, most domestic graduate students have serious gaps in their undergraduate education that need to be filled before they can compete with candidates from other countries in Europe, the Middle East, and Southeast Asia. Thus, as instructors involved in research, we also have an obligation to ensure that students are indeed ready for challenging graduate programs.

In the final analysis, as instructors of technological fields premised on the goal of making the world a better place for humanity, we have a professional and moral responsibility to educate students who can actively participate in and *direct* technological developments for a better future. To be able to do that, our students should not only know the knowledge base of the discipline but also be expert thinkers and life-long, self-learners.

3.2.3 From Industry's Perspective

It is common knowledge that most industries spend considerable time and resources to retrain many of our graduates. This state of affairs is in part perfectly acceptable and happens in many other fields. After all, one of the objectives of all engineering programs is to enable students to be retrained. The problem about which the industry complains is that most graduates of engineering programs are *not* armed with characteristics of being self-learners. Most of our students are bright but lack systematic training in thinking about problems, looking at different aspects, examining possible solutions creatively, suggesting and trying different approaches, and delivering one or a few solutions. In most instances, blind imitators need to be led most of their lives. They lack leadership skills, as they are not self motivators and are not careful and efficient thinkers. They merely know how to do what has been done. Consequently, they cannot adapt to changes in technology, nor can they contribute to the process of change. Creative thinkers, or creative problem solvers, seek, discover, question, and test and go through this process many times. Such individuals are considered the most valuable assets in any industry.

3.2.4 From Society's Perspective

Finally from society's point of view, we believe that engineers have the responsibility of bettering the world by creating instruments, toys, roads, etc. that improve society. Consequently, the least we expect is to have well-rounded engineers who are competent in their trades, responsible in their actions, creative in their thinking, ethical in their lives, and dependable members of their profession as well as of society.

People who can only do what they are told to or engineers who can only mimic what has been done before cannot learn from their mistakes. We need practical engineers whose actions are informed by a broad education, who learn from their mistakes, and who can improve their approaches to problems based on their findings. Blind imitators are doomed to repeat mistakes and hinder the progress (technological and otherwise) of societies.

3.2.5 Physician Heal Thy Self

Of course, the problem we have identified in engineering education creates a challenge to engineering educators that requires a degree of self-reflexivity. We often resign ourselves to blaming students and their attitudes or socio-economic conditions. Surely, these are contributing causes, but we cannot stop at identifying and studying causes. We need effective solutions. We also cannot go about solving this problem the way engineering imitators might. Most engineering programs are trying their best to fit more in the engineering curricula and to expose students to more material. But this approach has been tried for a long time, without significant success. We need new approaches.

In order to get a fresh look at the problem and possible solutions, we propose to look at the problem we have identified through the lens of John Dewey's philosophy of education and theory of inquiry. The influence of John Dewey, a foremost American philosopher in the tradition of pragmatism, on every level of the education system in the United States has been immeasurable. And his theory of education, which emphasizes a broad liberal education but through goal-oriented, hands-on, practical, and game-like activities of students is particularly relevant to engineering education.

4. John Dewey's Philosophy

In presenting an overview of Dewey's philosophy of education and theory of inquiry[3-8], we see an answer to this question: "What would John Dewey observe, criticize, and suggest regarding the current engineering programs?" We will keep our focus on the connections between Dewey's ideas on critical or reflective thinking and the problem-solving skills that engineering students are expected to learn.

4.1 Dewey's Central Concern: The Formation of Good Ideas

Dewey's central concern, the major problem he grappled with at every level of analysis—whether educational, scientific, aesthetic, political, etc.—is how we can ensure arriving at good ideas, which he defines very broadly: depictions, words, explanations, mental images, etc. He wants to know how in goal-oriented, communal (conjoint or cooperative) activities of humans made possible through communication, we can ensure that we are successful in taking the most important step—arriving at good ideas—in surmounting difficulties and in solving problems.

He believes that not just the happiness and prosperity but the very survival of the individual and of society depends on the success of humans in forming good ideas: solutions, decisions, depictions, explanations, etc. But he is not merely content to create a social formation that permits a one-time or short-term realization of those goals. Rather, his philosophy aims at creating conditions that ensure the *continued* possibility of realizing those goals. Thus he is after mindsets, mechanisms, and approaches to knowledge creation that are self-correcting, combat intellectual ossification, and resist creation of disciplinary orthodoxy and dogma. In short, he envisions a society in which the idea and practice of *reform* are deeply incorporated. His epistemological and political models for achieving these goals are scientific and democratic, respectively. Moreover, as will become clear shortly, his theory of inquiry and his philosophy of education have close affinities with engineering.

4.2 Organism and Equilibrium

Dewey's philosophy is based on his observations of the living organism. In *Logic: The Theory of Inquiry*, he argues that organisms already always live within an environment. Through the activities of organisms, they and their environments change, and adjust to, each other; thus organisms are in a state of flux and movement. A key characteristic of organisms is that in order for them to maintain life they have to seek equilibrium with the environment through activity and creation of change in the environment. They come out of balance with their environment (they become hungry, are threatened or hurt, etc.), and they seek to restore the balance. This *seeking* to restore balance marks for Dewey a foreshadowing of his theory of inquiry. For example, when an animal is hungry, it will look around and search for food. Through experience of finding food, it forms a store of knowledge, in some animals in the form of useful habits and in higher-order animals and specially humans in the form of both useful habits but also a store of memories[4].

Organisms through their movement to and from disequilibrium and equilibrium refine and improve their methods. He refers to this continual refinement and improvement as "growth." Thus, in *Democracy and Education*, Dewey writes that the aim of life is growth, which he defines as "a self-renewing process through action upon the environment" [5]. In *Reconstruction in Philosophy*, he writes that

> The process of growth, of improvement and progress, rather than the static outcome and result, becomes the significant thing. . . . Not perfection as a final goal, but the ever-enduring process of perfecting, maturing, refining is the aim in living. Honesty, industry, temperance, justice, like health, wealth and learning, are not goods to be possessed as they would be if they expressed fixed ends to be attained. They are directions of change in the quality of experience. [6]

4.3 Organism, Language, Culture, Communal Activity

Dewey maintains that in the communal activities involved in the pursuit of equilibrium, humans have come to communicate and use language. Several important features of Dewey's philosophy find expression in the previous sentence. First, language, according to Dewey, is bound up with (or subsumed under) action. Second, actions aimed at solving problems are social or communal. He defines language broadly to include "all means of communication such as, for example, monuments, rituals, and formalized arts . . Language is the record that perpetuates occurrences and renders them amenable to public consideration" [7]. He writes that the meaning communicated through language "is established by agreements of different persons in existential activities having reference to existential consequences" [7]. Through language, we evoke "different activities performed by different persons so as to produce consequences that are shared by all the participants in the conjoint undertaking" [7]

By emphasizing the *commun-* in communication and the development of language, Dewey underscores the intimate connection among community, language, and *thinking*. According to Dewey, the human ability to think is "a product of the fact that individuals live in a cultural environment. Such living compels them to assume in their behavior the standpoint of customs, beliefs, institutions, meanings and projects which are at least relatively general and objective" [5].

4.4 The 5-step Process of Inquiry—or critical thinking

In this model, the formation of ideas is the pivotal stage for humans in completing the communal activity. Stripped of his broader philosophical outlook, this pivotal stage (or Dewey's theory of inquiry) is the familiar scientific method, which he variously calls the process of inquiry, critical or reflective thinking, or a complete act of thought (*How We Think*). The five steps he uses are very similar to the steps involved in problem solving that engineering programs teach students. Dewey's five steps to thinking are "(i) a felt difficulty; (ii) its location and definition; (iii) suggestion of possible solutions; (iv) development by reasoning of the bearings of the suggestion; (v) further observation and experiment leading to its acceptance or rejection; that is, the conclusion of belief or disbelief" [5].

A complete act of thought begins with a problem. The problem itself arises from already on-going activities of the inquirer. Dewey considers step (iii), suggestion, "the very heart of inference; it involves going from what is present to something absent. Hence, it is more or less speculative, adventurous. . . . .The Suggested conclusion so far as it is not accepted but only tentatively entertained constitutes an idea. Synonyms for this are supposition, conjecture, guess, hypothesis, and (in elaborate cases) theory" [7]. On step (iv), reasoning, he writes, "The process of developing the bearings--or, as they are more technically termed, the implications--of any idea with respect to any problem, is termed reasoning. As an idea is inferred from given facts, so reasoning sets out from an idea" [7]. On steps (ii) and (v), he writes (*Logic*) that in "the more complex organisms, the activity of search [ii and v] involves modifications of the old environment [the environment in which the problem has been encountered], if only by a change in the connection of the organism with it" [7]. In other words, steps (ii) and (v) require "the transformation of the situation . . . . [which] is existential and hence temporal" [6]. In the search, the inquirer goes to and in the process changes or interacts with the environment.

5. Education and Reform in Dewey

Dewey is, first and foremost, a reformer.

5.1 Goal of Education for Individual: True Freedom or Self-Control

In *Experience and Education*, Dewey argues that in a sense, a good education aims to free students of their impulses (see next subsection for his ideas on growth). But he writes that the real freedom is a "power to frame purposes, to judge wisely, to evaluate desires by the consequences which will result from acting upon them; power to select and order means to carry chosen ends into operation" [7].

For Dewey, the starting point of all knowledge is the lived experience of the individual in the world of the common sense. For science, the starting point has always been common sense, and often science has to return to its common sense roots to find its footing. For individuals, knowledge begins from what they value and already understand of their lives. He writes, "Natural impulses and desires constitute in any case the starting point. But there is no intellectual growth without some reconstruction, some remaking, of impulses and desires" [7]. Dewey is concerned that individuals in society and in school often do things either impulsively or by force of authority. The external constraint imposed by society is useful in that it moderates and controls impulse. But he believes the better source of constraint or "inhibition" is through one's own reflective or critical thinking [7]. In a memorable passage, Dewey writes,

> thinking is stoppage of the immediate manifestation of impulse until that impulse has been brought into connection with other possible tendencies to action so that a more comprehensive and coherent plan of activity is formed. Some of the other tendencies to action lead to use of eye, ear, and hand to observe objective conditions; others result in recall of what has happened in the past. Thinking is thus a postponement of immediate action, while it effects internal control of impulse through a union of observation and memory, this union being the heart of reflection. What has been said explains the meaning of the well-worn phrase "self-control." The ideal aim of education is creation of power of self-control. [7]

5.2 Goal of Education for Society: Creating Conditions of Continued Growth

Dewey believes that through the exercise of intelligent freedom or "self-control," students may be in the best position to ensure continued conditions of growth. In *John Dewey and the Challenge of Classroom Practice*, Stephen Fishman and Lucille McCarthy write that, according to Dewey, education should provide conditions of growth and develop characteristics that provide further opportunities for continued growth[8]. Dewey's educational goal is all around growth, not just for students but for society (*Democracy and Education* [5]). And again by growth he means a type of interaction with the environment through which both the organism and the environment mutually adapt to and shape each other. He wants to provide society with what it needs to perpetuate itself, to create conditions of growth that are most conducive to further growth.

Dewey believes that the social (and institutional) arrangement that can best create such conditions of growth is democracy, with ever greater intelligent participation of members. Through open channels of communication and commitment to dialogue and criticism, Dewey hopes that both society and the individual can create conditions conducive to forming good ideas. These good ideas will lead to better decisions that result in greater flourishing and development of the individual. Through the process of open communication (as part of society's general projects of inquiry), both the individual and society will be transformed for the better

6. Implications of Dewey's Theory of Inquiry for Education

There are several aspects of Dewey's theory that are important for engineering education.

First, Dewey argues that knowledge never leaves the realm of theory and remains forever subject to change. No matter how certain scientists and engineers are about a theory they use to explain their activities and their decisions, a theory never leaves the realm of "guess," and scientists should forever leave open the possibility that their firmest ideas and most cherished solutions may need to be modified or scrapped. The effectiveness of science and engineering emanates exactly from this characteristic of science. And engineers and scientists would do well to pass on this mindset to their students by creating an environment that genuinely encourages this skeptical attitude in students. This encouragement does not mean paying lipservice to the idea. The attitude can only be adopted in practice. Students need a safe environment and enough time and resources to question and reject received explanations and to attempt to find better ones.

Second, Dewey argues that all inquiry involves transforming the environment; it is an activity. Knowledge making is by definition transformative. The type and extent of transformation, of course, has to do with the goals of inquiry. For Dewey, an inquiring mind is going to change the environment in some way, disrupt the old ways of doing things. It will be respectful of past ways of doing things but will not worship and revere those ways so much so as not to try new ways. Thus, the educational environment should anticipate, encourage, and adapt to such changes. Instructors may have to change their syllabi, their projects, their overall teaching strategies, etc. Or they may have to gear their instructions to specific needs of students. Departments need to understand this necessary step in inquiry and accommodate instructors. Such changes cost money and resources, but if the goal is the teaching of *thinking*, then Dewey at least would argue that the cost is well spent, since the alternative is directly inimical to thinking.

Third, Dewey argues that facts are facts in the context of inquiry. They are "operational . . . . [and] not self-sufficient and complete in themselves. They are selected and described . . . for a purpose, namely statement of the problem involved in such a way that its material both indicates a meaning relevant to resolution of the difficulty and serves to test its worth" [4]. The implication of this position is that the teaching of facts outside the context of inquiry is counterproductive. Schools spend a great deal of time teaching facts outside the context of inquiry. And students spend much of their time memorizing such facts, which they promptly forget after tests. If the inquiry genuinely matters to students, they will seek out the facts and remember them long after the problem has been solved.

Fourth, Dewey argues, "science takes its departure from commonsense," which consists of "beliefs, conceptions, customs and institutions" [7]. Dewey emphatically argues against teaching to students the findings of science as ready-made ideas to believe in. It is not enough merely to repeat that all findings of science are hypothetical or theoretical. Rather, students should come to see the theory in the context of a meaningful inquiry. Only while the theory plays its function in the process of inquiry can it be understood as did the scientists who came up with the theory and examined it in the first place. If the curriculum is to succeed in creating conditions in which an accelerated process of real inquiry (an inquiry that matters to the student in that the student has ownership over the problem the theory tries to solve), then of course the student should also be encouraged to doubt and question the theory.

But there is a much deeper issue implied in the observation that the starting point of science is the world of commonsense. For the student, a theory thought outside the context of inquiry remains a dogma, and a student who believes in it has practiced exactly what science is designed to circumvent: accepting claims on mere authority, that is, accepting claims without examining the reasons and evidence. Here Dewey makes an important observation. He argues that students accept such dogmas because the subject matter of inquiry does not matter to them. To say that an educator should create conditions in which the inquiring minds of students are engaged requires that problems be relevant and of importance to students; the problems should matter to students' lives; they should, one way or another, fit in with the broader circle of concerns of students' needs, aims, and values. For example, for Dewey, expecting students to register in classes for no other reason than that four years in the future they will be able to get a good job is tantamount to expecting students to engage in a set of activities that, for students, is not only *irrational* but detrimental to their intellectual development. To use Dewey's framework, students who engage in activities (processes of inquiry) whose purposes they do not understand are acting by means of external constraints. Students who do not understand and care for the problem cannot meaningfully search for possible solutions, formulate questions, and test their guesses. Consequently, their activities will be directed not because of the intelligent operations of their thoughts in an environment geared towards learning something about the subject-matter, but because they want to receive a certain grade, or to graduate and earn a certain amount of money, etc. In such a context, students are learning something, but what they are learning is that the subject matter is irrelevant to their lives and that if they wish to surmount a problem that does genuinely matter to them (receiving a good grade, a good job down the road, etc.), they have to engage in a set of irrational and arbitrary activities.

These considerations led Dewey to grapple with a very important problem in education: the connection between student interest and curriculum. When students enter a disciplinary discourse community such as electrical engineering, they are confronted with a set of disciplinary problems. If the problems the discipline is facing or has faced and solved are also not problems for students, they will not enter the process of inquiry. According to Dewey, an educational arrangement in which students do not find the subject-matter of study inherently interesting has failed on several levels, perhaps the most obvious being, the failure of the educational program to permit students to think.

But Dewey considers the harm done to the discipline and society equally disturbing. Given his belief in the urgent necessity of the possibility of continued reform (growth) both in science and in society, Dewey has a special esteem for schools, which he considers to be social spaces in which ideas about change in science and society can be formed and tested. Thus, Fishman writes that Dewey wants to develop an

> experimental spirit . . . in pupils. For . . . although Dewey cares a great deal about student mastery of subject matter--insisting that to be part of a community is to share common language, values, and practices--he is equally concerned that students develop critical methods or habits of thought so that communal traditions can be tested and revitalized. [8]

For Dewey, a genuine learning environment (a disciplinary discourse community) not only permits but encourages and expects challenges to its established views and assumptions and patterns of professional and administrative behavior.

7. Conclusion: So What Would Dewey Say?

We believe that Dewey would find the objectives of an engineering program to be in fundamental agreement with his own educational philosophy and his theory of inquiry in that both he and engineering programs aim to teach critical thinking: For Dewey, the process of inquiry, and for engineering programs, problem-solving skills (especially if broadly defined).

7.1 Overpacked curricula

But Dewey would find several problems in how engineering programs go about teaching critical thinking skills to their students. He would probably be alarmed by the over-packed curricula designed to expose the students to as much as they may need to know. He would be concerned about how this information is being learned, as part of a process of inquiry that matters to students or as part of an externally imposed requirement?

7.2 Lack of Flexibility

He would be concerned about the lack of flexibility due to the material and time constraints facing engineering departments. Such constraints discourage the free-play of ideas and criticism and discourage many bright students and dynamic thinkers.

7.3 Lack of Emphasis on the Discovery Aspect of Education

Dewey would find an inadequate emphasis on what we call the discovery aspect of education, that is, on giving students an opportunity to come up with and test their own guesses (solutions, hypothesis). Discovery is time consuming and expensive. Although some programs are changing for the better, Dewey would argue that without heavy emphasis in this area, students will not be able to hone their thinking skills, a disaster from his perspective.

7.4 Dewey Sees that We Teach Facts and Already formed Ideas instead of How to Form Ideas

Dewey would note that most of our curricula seem to have been designed for information exchange rather than for teaching systematic thinking processes, which lead to the discovery of other, broader problems and other inquiries.

7.5 Thus, Dewey, Would Say Our Failures Are Results of the Absence of Inquiry

Dewey would probably find the engineering programs and our teaching methods responsible for some of the behaviors we observe in our students. For example, Dewey would probably argue that our students' short attention spans and their lack of drive for improving their foundational knowledge in the discipline are all due overpacked and inflexible curricula that do not permit students to inquire, question, discover, learn, and become dynamic life-long learners.

One of the many attractions of Dewey's philosophy of education is its persistent focus on understanding and solving the very many obstacles confronting a teacher of *good thinking*, among whom engineering instructors find themselves.

8. References

1. Dekker, D.L. "Engineering design processes, problem solving and creativity," *Proceedings Frontiers in Education Conference*, Vol. 1 , 1-4 Nov 1995, pp. 3a5.16 -3a5.19 vol.1
2. Yokomoto, C.F,; Voltmer, D.R,; Ware, R." Incorporating the "aha!" experience into the classroom and laboratory," *Proceedings to Twenty-Third Annual Frontiers in Education Conference 'Engineering Education: Renewing America's Technology', 1993.*, 6-9 Nov 1993, pp. 200 -203
3. Dewey, John, *How We Think*. New York: Prometheus Books. 1991.
4. Dewey, John. *Logic: The Theory of Inquiry.* New York: Holt, Rinehart and Winston. 1938.
5. Dewey, John. *Democracy and Education.* New York: The Free Press. 1916
6. Dewey, John. *Reconstruction in Philosophy.* Boston: Milton Balch. 1962.
7. Dewey, John. *Experience and Education.* New York: Touchstone. 1936
8. Fishman, Stephen, and McCarthy, Lucille. *John Dewey and the Challenge of Classroom Practice*. New York: Teachers College Press. 1998.

Biographical Information

MANI MINA is an adjunct assistant professor at the Department of Electrical Engineering and Computer Engineering at Iowa State University. He has been a recipient of several teaching and research awards. His research interests include optical networking and communication and innovative methods of teaching technology. He is an active member of IEEE and American Society for Nondestructive Test (ASNT).

IRAJ OMIDVAR is a doctoral student in rhetoric and professional communication in the Department of English at Iowa State University. He has received the Outstanding Innovations Award, Iowa State University Learning Community institute, the Outstanding Faculty Award, Interfraternity Council and Collegiate Panhellenic Council, and the Premium for Academic Excellence Award, Iowa State University.

KATHLEEN KNOTT is a master's student in Higher Education at Iowa State University. She received her B.S. in electrical engineering in 2001. Her interests include research in the foundations in education.