Variations in student learning in an inquiry-based freshmen electrical engineering course

Neelam Prabhu Gaunkar
Department of Electrical and Computer Engineering
Iowa State University
Ames, Iowa 50011
Email:neelampg@iastate.edu

Melissa Rands
Department of Academic Affairs
Minneapolis College of Art and Design
Minneapolis, MN 55404
Email: mrands@mcad.edu

Mani Mina
Departments of Industrial Design and Electrical and Computer Engineering
Iowa State University
Ames, Iowa 50011
Email:mmina@iastate.edu

***Abstract*—In this work, effects of inquiry cycles on freshmen engineers are evaluated. In particular reflection based methods are studied and discussed. The paper summarizes our early findings of a phenomenographical analysis of student reflections. A first year engineering course was designed as Deweyean inquiry-base class allows freshmen engineers to think, learn and engage with old and new concepts while developing aptitude for systematic thinking, problem solving and critical thinking. Students' reflections were analyzed at different points in time during the semester and selected keywords were phenomenographically classified into superficial and deep learning. Our assessment shows that most students were initially in the lower stages of learning and describing, and by adopting reflective practices students could move to higher learning stages. However, design of reflection questions and instruction styles do need to be modified to assist superficial learners to modify their learning methods.**

I. Introduction

An inquiry-based course is designed for first-year electrical engineering students' to develop their critical thinking abilities. The designed course is based on Deweyan cycles of inquiry enabling freshmen engineers to engage in critical thinking, learn problem solving, develop aptitude for systematic thinking and other abilities suited for engineering. The inquiry method relies on engaging students in continuous process of questioning and reflecting. This cyclical format allows students to review, re-examine and reframe their conceptual understandings. Previous works [1], [2], [3] highlight the fundamentals of reflection and inquiry. There are many references in the use of reflection in engineering classes [4], [5], [6], [7].

II. Deweyan cycle of inquiry

The basic Deweyan cycle of inquiry has been discussed in literature [8], [9]. The process of inquiry begins with a felt difficulty. Then the location and definition of the problem are examined. This leads to suggestion of possible solutions. By examining the suggestions one develops reasoning of the bearings of the suggestions. Finally further observations and experimentation's lead to acceptance or rejection of the solution. At this level the inquirer will have a set of conclusions that will naturally result in beliefs and disbelief's. The students are encouraged to always keep the inquiry cycle alive. They are also encouraged to examine beliefs and disbelief's in such cycles. In this process effective reflection is essential for the students to improve their thinking, questioning and critical thinking [4].

III. Need for inquiry at freshmen level

Freshmen introductory courses have been considered to be transformative by nature [10], [11], [12], [13], [14]. Our study was purposefully implemented in a freshmen level introductory course since freshmen students have pre-conceived notions about engineering, have formed specific methods of learning, memorizing and thinking from their schooling experiences. To be a part of the engineering community and learn new ways, it is necessary that the students change or modify some of their previous methods. Most importantly, previous studies have shown that freshmen courses allow students to relate to the field of study, create a sense of belonging, and define a deeper learning purpose and trajectory for their future endeavors in engineering [15]. Thus, as freshmen instructors, it is necessary to create memorable and meaningful experiences, let the students feel involved, assist them in forming ideas, developing metacognitive abilities and at the same time allow them to go above and beyond what they have previously learned. Inquiry-based methods could allow them to easily adapt and transition to university education [16], [17].

A. Student inquiry cycle

For this project, the student (inquirer) experiences a problem (a difficulty) and investigates methods to solve it. The inquirer engages in discussions with peers, self-reflects and creates new ideas, solutions and questions. This is the initial cycle of inquiry. When the inquirer is presented with the problem again since they have previously engaged with the cycle of inquiry, they build on their prior understanding, build connections and invariably practice metacognition through iterative inquiry cycles.

B. Assessing student reflections

An assessment on variations in students conceptions towards problem solving as a result of inquiry-based interventions during the freshmen electrical engineering course was performed. Our primary focus was to understand the effect of reflective

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practices [4], [18], [19], [20] on the students' problem solving capabilities. A challenge of traditional assessment methods such as tests, quizzes and homework's is that they are not necessarily effective indicators of the students' learning and growth in an inquiry-based atmosphere [21]. Multiple rubrics [22], [23] and assessment methods [24] have been proposed and in this work the students reflections were analyzed using a phenomenographical [25], [26], [27] approach that categorized the written responses from superficial to deep conceptions of the phenomenon. In this work, a record of conceptual changes in students understanding of fundamental electrical engineering concepts and problem solving abilities and the nature of the changes and an estimate of shifts in students' understanding over the course of the semester is presented.

IV. Research Framework

Based on Dewey's ideas on inquiry-based learning, and prior work by Mina et.al [4], [22], this research project is focused on evaluation of individual student reflections/quizzes. A random sample of 15-20 (based on in-class attendance) students were selected from one section of the course, and included U.S. and international students. Assessment reflections were collected from students at different time points. The assessments were weekly group and individual reflections (and some in class quizzes). For this particular evaluation, a set of questions were (designed and) presented to the students at two different stages during the semester. The students developed sufficient familiarity with the basic concepts and principles, before the second intervention. The students responses were carefully studied and categorized into different learning segments ranging from superficial learning to deeper learning as described in Entwistles writings on phenomenography [25]. The course instructor and mentors have defined the coding protocol as described in section V. One of the key objectives for the course is that the students specifically focus on learning by forming a conceptual model of their own learning in their minds. While most of the concepts discussed and presented in class are not new for the students, the methods and approaches are in most cases different from their prior experiences. The students are thus encouraged to discuss, re-examine and raise questions about the concepts they learn. This method helps students in creating their own vocabulary and learning experience and is effective for developing their learning.

V. Assessment Method

For the phenomenographic evaluation method, an important aspect of reflection-based activities is that they are more open-ended. They do not necessitate a fixed definite answer. Instead, the students have to display their method of thinking, form their ideas and analyze the problem at hand. The students have presented their views and debated their opinions. The assessment focuses on how they communicate their problem solving skills through the entire problem-solving process. In this work in progress article our focus is on developing a method for analyzing reflection-based activities.

A. Assessment: Questions

The students were presented with two different questions to reflect upon. The first question, described below, is based on their interpretation of rectangular and polar form of Euler's equation.

Question 1: Given the following (r, θ) and $re^{j\theta}$

a. Discuss if these are the same?
b. Is the information in them the same?
c. Why do we use Eulers form how does it help us?

The second problem is a correlation/causation problem designed to test their ability in forming an opinion.

Question 2: Would you, as a cellphone user, believe in any of these claims? Would you investigate any of them further? Why or why not?

a. **Claim 1:** *The **American Cancer Society (ACS)** states that the IARC classification means that there could be some cancer risk associated with radio frequency energy, but the evidence is not strong enough to be considered causal and needs to be investigated further. Individuals who are concerned about radio frequency energy exposure can limit their exposure, including using an ear piece and limiting cell phone use, particularly among children.*
b. **Claim 2:** *The **Federal Communications Commission (FCC)** concludes that no scientific evidence establishes a causal link between wireless device use and cancer or other illnesses.*

Evaluation of stage 1 of these questions revealed that Question 1 had to be rephrased to probe the students' to think and move to deeper cycles of learning. Question 1 was then rephrased as Question 3 below:

Question 3: We have been talking about these two forms (r, θ) and $re^{j\theta}$

a. What do you think about these two forms? Reflect and write about your thoughts and ideas about these two forms.
b. In electrical engineering why do we use these forms? Reflect and write about your thoughts about them.

B. Assessment: Learning Levels

From the first set of student reflections, common themes and keywords that repeated between different students were tracked for both the questions. As guided by Krathwohl [28] and adaptations to suit engineering students the themes were classified into learning stages in coherence with the stages proposed by the revised Bloom's taxonomy [29]. An additional stage, Opposing, was included to classify student reflections that showed low student engagement or interest in the questions.

- **Superficial Stages**

a. **Opposing** - Students refuse to engage with the questions or cycle of inquiry
b. **Repeating/Remembering** - Students agree/repeat claims in the question
c. **Describing/Understanding** - Students understand the questions and describe their thoughts

- **Deeper Stages**

d. **Applying** - Students are connecting the different concepts they have learned

e. **Evaluating** - Students are developing a thought process and are re-examining their prior ideas

f. **Critiquing/Self-Aware** - Students understand the process, they are engaged in the cycle of inquiry and are questioning all aspects

While further sub-categories are possible, these levels align well with surface and deep learning as defined in the phenomenographic method. Overall, our efforts are directed towards tracking the students' progress in the class as well as their growth in critical thinking and self-learning. The described learning levels serve as a benchmark in understanding how a students' learning develops over the duration of the course. This includes the students ability to learn from diverse perspectives, reflect and updating their own ideas based on their perspectives, questions and team discussions. These cycles of active learning have proved to be beneficial in prior work by Prince [30] and should be effective in our study as well. Consequently, the reflections will help us track both the students' critical thinking ability and growth towards self-learning and thus contribute to modifications of teaching methods/process to help students engage, explore and understand more. Moreover methods to empower students to communicate via team discussions can be developed.

VI. Analysis

As discussed in section IV students were presented with the same set of questions at different stages during the semester. The research questions were designed to be open-ended and reflective instead of exact solution problems.

The students responses were collected and analyzed over different interventions. Keywords in their reflections were categorized into the different learning stages as described in Tables VI-A and VI-B respectively.

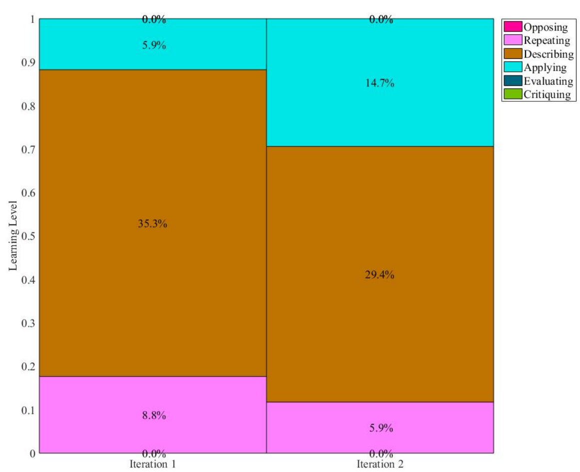

Fig. 1. Variation in responses for Q1(a) over different iterations. Only three learning stages are observed. The missing stages are represented with 0%

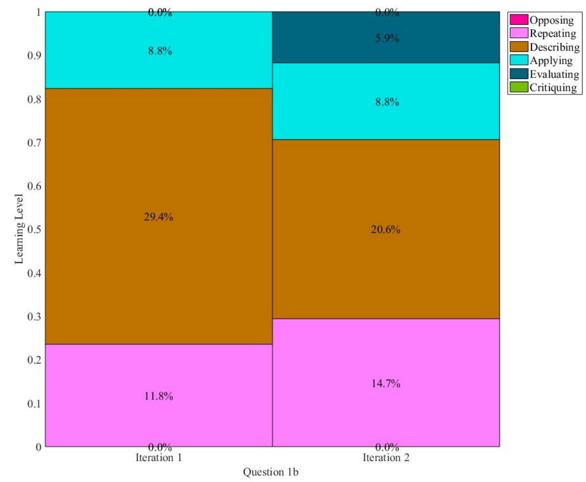

Fig. 2. Responses for Q1(b) over different iterations.

On the basis of the learner coding scheme, the variation in students' learning in the aspect of problem solving and interpretation (Question 1) and the aspect of decision making (Question 2) may be summarized in Fig. 1, 2, 3 and Fig. 5 respectively. The height and percentage of each box represents the proportion of individuals in the particular learning level. The scale on the y-axis represents the response probability with the axis being a probability of 1. From Fig. 1, 2, 3 we found that students' were unable to transition to higher learning stages for Question 1 and most students' were predominantly describing what they had learned. However, for Question 2 many of the students' were in the evaluation stage. This finding led us to modify Question 1 and re-examine the students' knowledge base. The results are summarized in Fig. 4.

A. *Question 1 and 3: Learning stages vs keywords*

Stage	**Expected Keyword**	**Actual Keyword**
Opposing	Don't know/care	Don't remember, Will find out
Repeating	Are the same (Yes/No), Same information	Not exactly/Are the same, Very similar, Same information
Describing	Imaginary, Polar representation	Imaginary, Pythagorean identities, There is 'j'
Applying	Quadrant information, Can find components	Interchangeable, Angle, Magnitude
Evaluating	Faster calculations	Different forms, complex is better
Critiquing	Difference between forms, applications	Possible applications, utility

B. Question 2: Learning stages vs keywords

Stage	Expected Keyword	Actual Keyword
Opposing	Don't believe, Won't investigate further	Wouldn't believe or cannot do much
Repeating	Will limit exposure, Causal link	Hard to remove, Limit exposure
Describing	Radiation harmful, Weak evidence, Believe	Believe, Compare to others, Organization reputation
Applying	Minimize use, Check claim, references	Statistics Investigate, Evidence, Would check radiation
Evaluating	Find out, interpret resources, Non conclusive	Will research myself, Find credible claims, Informed decision
Critiquing	Investigate more, Evaluate effects	Peer reviewed claims, difficult to generalize

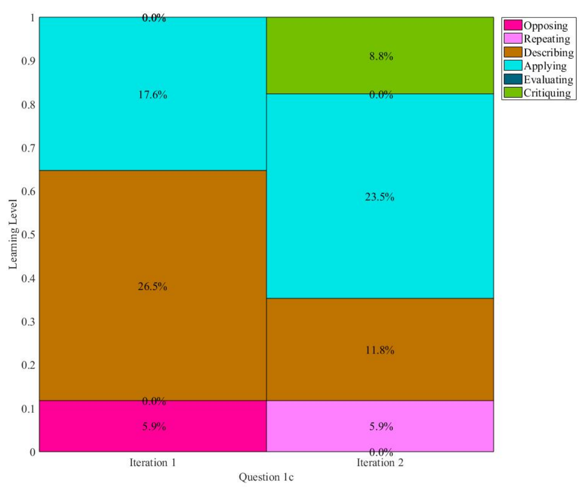

Fig. 3. Responses for Q1(c) over different iterations. It is observed that several students were able to transition to critiquing after the question was rephrased

Fig. 5 summarizes the findings from the for Question 2. Many students' have transition to deeper learning stages even in this case. Overall, it is observed that with reflective practices over the course of the semester there was a shift in the students' perception about their learning. Many students' were able to transition from superficial learning stages (Opposing, repeating, describing) to higher stages (Applying, evaluating and critiquing). While these transitions were affected by the way the questions were posed it remains to be seen if the students' actually went and researched the claims (as proposed in Question 2) or were reflecting on what they should do.

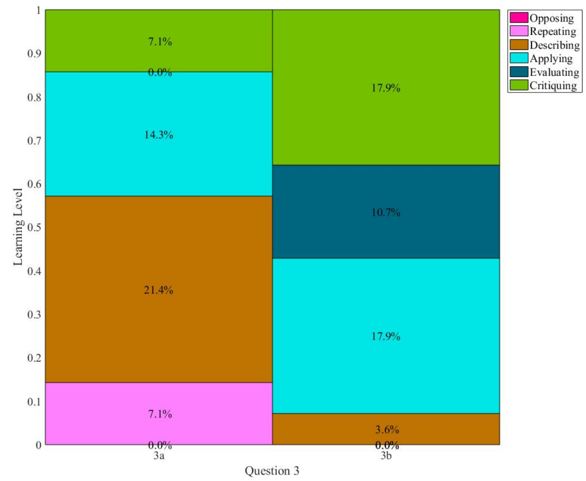

Fig. 4. Results after rephrasing Question 1. Here we find that several students' have transitioned to applying, evaluating and critiquing their learning

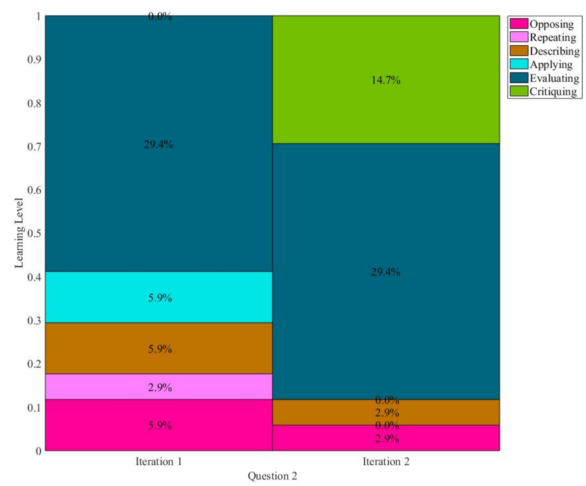

Fig. 5. Variation in responses for Q2 over different iterations. Initially most students are evaluating and some transition to critiquing

VII. Conclusions

The findings of the study include several messages for freshmen instructors and evaluators adopting inquiry-based techniques. Student responses are severely affected by the design of the questions and in particular their interpretations of the questions. In order to assess deeper learning aspects and critical thinking, the questions need to be redesigned to test the students abilities in applying fundamental concepts to particular applications [31]. While this assessment is ongoing, the initial findings are encouraging and show that student learning is impacted by awareness of their learning methods, reflective practices, teamwork and engagement in metacognitive thinking cycles.Through the assessment findings, instructors would be able to reiterate teaching methods and promote deeper learning methods.

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