Using the Five Whys Method in the Classroom: How to Turn Students into Problem Solvers

Saeed Moaveni
Minnesota State University

Karen C. Chou
Northwestern University

Abstract

In engineering practice, unfulfilled customer needs must be addressed or else the company will lose business. When a product malfunctions or does not meet the design standards, the engineers who designed the product need to fix the problem. Simply stated, the engineers need to go back and figure out what went wrong and fix it. Unfortunately, in engineering education, we do not emphasize this important fact enough. As instructors we correct students' homework, quizzes, reports, and exams, and return them without asking students to go back to determine on their own, what they did wrong. During the past few decades, a lot of attention has been devoted to root cause analysis and structured problem solving techniques. One such technique is called the *Five Whys*, which is used by many global corporations including Toyota and IBM to solve problems. The *Five* is an arbitrary number that is intended to promote deeper probing into the root cause of a problem by asking many *Whys*. During 2012-2015 academic years, this technique was used in five upper-level civil engineering classes at Northwestern University to get the students to work out, on their own, what they did wrong in homework assignments and fix them. The instructor in the course acted as the customer or the client who was unhappy with the performance of a product, the homework. As shown in this article, the results of this 3-year study are promising. The results show that using the Five Whys method students learn from their mistakes more effectively and this method better prepares them, as problem solvers, for the practice of engineering. The challenges of using the Five Whys technique to turn students into problem solvers on their own are also presented in this paper.

Introduction

Before we introduce a new learning structure such as the *Five Whys*, we must first take time to understand today's students. Many of us (the faculty) belong to the baby boom generation. We were taught using blackboards, black and white textbooks with few illustrations, and we studied by ourselves to understand new materials. Today's students, on the other hand, are accustomed to smartboards, multimedia presentations, multi-color eBooks with videos, and belong to online social networks [1-2]. Over the years, online social spaces such as Facebook have evolved as a communication platforms through which students share information. Even though a network such as Facebook was initially conceived purely as a social space, it is now used to engage students in classroom activities. Many researchers have measured the effectiveness of Facebook groups that were created for their courses and reported that students who participated in the Facebook groups enjoyed the courses more, felt a stronger sense of belonging, and received better grades than those who did not participate. The research supports the argument for using a social media such as Facebook for engaging students and increasing retention [3-5]. In recent decades, researchers also have conducted numerous studies dealing with how people learn [6-16]. One of the key characteristics of learning as discussed by Branford et al. [6] is that initial learning is necessary for transfer. In other words, applying previous knowledge in acquiring new knowledge is essential [6,14]. These studies show the benefit of thorough understanding to transfer, and confirm that learners are more motivated when they can see the usefulness of what they are learning [14]. For example, students enjoy courses that have hands-on design activities. Courses with design projects give students the opportunity to examine on their own if their design functions properly; if not, students work intensely by themselves to find the source of a problem and modify their design until it functions satisfactorily. Unfortunately, the process of getting students to find their own mistakes and correct them – a process which is fundamental to practice of engineering – does not exist in most of the engineering courses, particularly the analysis courses.

In this article we discuss the Five Whys method, which is used by many global corporations to solve problems, and describe the approach that we took to adopt the Five Whys method in different engineering courses to get students to find their own mistakes and correct them.

The Five Whys Method in Engineering Practice

As mentioned previously, in engineering practice, unfulfilled customer needs must be addressed or else the company will lose business. When a product fails or when it does not meet design conditions or standards, the engineers who designed the product need to fix the problem. Simply stated, the engineers need to go back and figure out what went wrong and fix it. In fact, many global corporations, such as IBM, hold annual meetings to bring their engineers together to share how problems were solved and what steps will be taken to avoid similar problems in the future. Again, in engineering education, we do not emphasize this type of approach. As educators we correct (grade) students' homework, quizzes, reports, and exams, and return them without asking students to go back to determine, on their own, what they did wrong. In most instances, students would focus on their scores and look at the instructor's comments briefly. Rarely would they examine the comments carefully and probe deeply to find the root cause of their mistakes. As the result, students would repeat their mistakes and would not develop the deep understanding of the fundamental concepts necessary for transfer to other topics.

During the past few decades, a great deal of attention have been devoted to root cause analysis and structured problem solving techniques [17-20]. One such technique is called the *Five Whys*, which is used by many global corporations to solve problems. The Five Whys method was initially developed by the Toyota Motor Corporation. The *Five* is an arbitrary number that is intended to promote deeper probing into the root cause of a problem by asking many *Whys*. Moreover, the Five Whys technique works best, when it is done in a team-setting by a group of people with complementary expertise. The approach also requires a team that can define the problem clearly. Once the problem is identified, the first *why* question is asked and the plausible answers are recorded, then four additional *why* questions are asked and answered. During this process, all credible answers must be recorded for further evaluation to arrive at the root cause. After the probable root cause is identified, corrective actions must be taken, so that the problem will not occur again.

The Five Whys Method in Classroom

After an exhaustive literature search and to the best of the authors' knowledge, no investigator has applied the

Five Whys approach to engineering education. From this perspective alone, this study will add to the existing body of knowledge. The study is also creative and original in that it makes use of a powerful technique used by global corporations to solve problems and train better engineers.

To prepare students to become better problem solvers, during 2012-2015 academic years, we used the Five Whys method in five civil engineering classes and got students to work out on their own what they did wrong in their homework assignments and fix them. The classes included introductory and intermediate level analysis and design courses. The instructor in the course acted as the customer or the client who was unhappy with the performance of the product (the homework assignment). The results of the studies pertaining to today's students' preferences and learning styles, discussed in the introduction section, were also considered when applying the Five Whys method.

At the beginning of the academic term, students were introduced to the Five Whys method by stating that: *"In an attempt to better prepare you to join the engineering profession, a new active learning concept is implemented in this course. This new concept requires you to take a more active role in identifying your own mistakes, correcting them, and stating how to prevent similar mistakes from happing in the future."* The information shown in Figure 1 was also distributed to the students and discussed. After the "Five Whys" method was introduced in the class, we implemented it in the following manner:

- Each group of two students formed a team and submitted their homework assignments.
- If the submitted assignment had mistakes, the instructor (the customer) informed the students who acted as engineers that their assignment or the product had faults and that they need to figure out where the problems were.
- Students were asked to follow the Five Whys method to identify their mistakes and correct them. Students also were asked to submit a record of their Five Whys approach. They submitted the Five Why questions they had asked and answered along with their revised solution. The members of the team had to reach an agreement as to what the root cause of the problems was. Each student in the group was to write down the solutions and why the problems or the mistakes occurred.
- After the problems were solved to the satisfaction of the instructor, the team then had to discuss how to prevent the problems from happening again.

The Assessment of the Five Whys Method in Classroom

The Five Whys approach and its effectiveness were tested in five civil engineering classes (67 undergraduate

For the Five Whys method to work, you and your teammate have to clearly state the problem, ask questions, and <u>honestly</u> answer them. Moreover, you must have the <u>willpower</u> to get to the root cause of the problem and the <u>self-discipline</u> to solve it. Please note that during the Five Whys process, all credible answers must be recorded for further evaluation to arrive at the root cause. To use the Five Whys method, you start with the end result, the problem; you think about what caused the incorrect end result and then you ask questions and record plausible answers. The following example demonstrates this approach. For this example, the end result is an incorrect solution to a homework problem by a student. Here are some reasonable questions asked by a student and likely answers by a teammate:

1. Why was this assignment marked as incorrect?
   Because we did not do the assignment correctly.

2. Why did we not do it correctly? [Note all plausible answers must be recorded and questioned with additional "Whys" until the root cause is determined.]
   a. Because we drew an incorrect Free Body Diagram (F.B.D.),
   b. Because we used a wrong concept,
   c. Because we made calculation errors,
   d. Because we made bad assumptions, or
   e. Because we did not understand the problem clearly,
   . . . .

3a. Why did we draw an incorrect Free Body Diagram?
    Because we forgot to include the reactive moment in the F.B.D.
3b. Why did we use a wrong concept?
    Because . . . .
    . . . .

4a. Why did we forget to include the reactive moment in the F.B.D.?
    Because we did not know that for a fixed support, we need to include a reactive moment.
    . . . .

5a. Why did we not know that for a fixed support we need to include a reactive moment?
    Because we did not study it carefully and did not think it was important,
    . . . .

The <u>root cause</u> for the above example is the lack of studying and adequate preparation before doing the assignment; to prevent this problem from occurring again, of course, the solution to this problem dictates that team members should study the concept related to the assignment carefully before doing the homework problem. Again, realize that for the Five Whys method to work, one has to clearly state the problem, <u>ask questions</u>, and <u>honestly answer</u> them. Moreover, it is important to have <u>the willpower</u> to get to the root cause of the problem and the self-discipline to solve it. As demonstrated by the example mentioned above, it is important not to stop at a symptom and proceed to the root cause. Moreover, you should think about what you learned from this root cause analysis, and what steps you are planning to take to prevent this type of problem from occurring again.

Figure 1. The Five Whys Method Information Sheet

and 6 graduate students, $n = 73$) during the $2012 - 2015$ academic years. In each class, the Five Whys technique was applied to weekly homework assignments. All homework assignments were done by teams of two students and reviewed in two rounds. In round one, the assignment was reviewed carefully but no grade was assigned; however, general comments regarding the mistakes were provided. Detailed comments and suggestions to fix the mistakes were not offered in this round. The students were given a second chance to determine where the mistakes occurred and correct them. Each team was required to submit a brief summary describing how the mistakes were identified — the Five Whys questions and answers — and how similar mistakes were to be prevented from recurring in the future. A grade was then assigned in this round based on the group's performance.

At the end of each term, the effectiveness of the Five Whys method was assessed through written surveys conducted by the faculty member teaching the class, and by interview of students guided by a researcher from the Northwestern University Searle Center for Advancing Learning and Teaching.

The Survey Form — A survey form was prepared by the authors of this article and distributed to students in each class. In the survey, the students were reminded to focus on the effectiveness of the Five Whys method — particularly in comparison to conventional grading methods — and not on the course itself. The survey consisted of three sections: (I) general information, (II) the effectiveness of a specific aspect of the Five Whys method, and (III) additional comments and suggestions for improvements. Regarding comments and suggestions, the students were directed to focus on providing feedback by listing the top three valuable attributes and the three least valuable at-

tributes of the Five Whys method.

The Interview – Sixty three students, who completed the Five Whys survey forms, also met with researchers from the Searle Center for Advancing Learning and Teaching and provided additional feedback. These researchers are trained to conduct student learning assessment interviews and to analyze the results. The focus of the interview was on student learning, and the three following questions were asked: (1) what aspects of this course enhance your learning? (2) How can this course be improved to enhance your learning? (3) What could you as a student do or continue to do to enhance learning in this course? It is important to note here that the students were not prompted to discuss any pre-determined aspect of the course that was assumed to enhance their learning. After discussing a question – for example, students working in groups of two to do a homework assignment and to resubmit the homework if incorrect – in small groups and then collectively, all participants came to a consensus on the aspects that they had agreed were most important. Comments collected during the interview were summarized by the researchers from the Searle Center.

Discussion of the Assessment Results

The first Five Whys effectiveness survey was conducted in a required reinforced concrete class with 18 civil engineering students in winter 2012. The result of this survey is shown in Table 1. The class performance may be summarized by a maximum course score of 98.3/100 by one student, a minimum course score of 42.3/100 by another student, and the class average of 73.6 with a standard deviation of 16. The bulk of the survey result shown in Table 1 is self-explanatory. However, the responses to questions 5 and 6 need further discussion. The response to question 5 is significant – **4.00** for Five Whys vs. **3.56** Traditional method – because the students see their test results as a true measure of their understanding of new materials and that the Five Whys method works for them. The response to question 6 [i.e., **3.83** vs. **3.39**] is also important because it is a measure of the students' assessment of the effectiveness of the method in reducing their recurring errors. It suggests that using the Five Whys method students learn from their mistakes more effectively.

Overall Student Survey Results – As mentioned previously, during the 2012-2015 academic years, a total of 73 students participated in the Five Whys study. The overall survey result is shown in Table 2. As shown in Table 2, during the study period, eighteen of the students were exposed to the Five Whys method more than once. Again, the bulk of the survey results is self-explanatory, and the responses to questions 5 and 6 stand out. The Five Whys method again scored higher than conventional approach, for question 5 [**4.01** vs. **3.58**], and for question 6 [**3.93** vs. **3.29**]. Once again, the results suggest that the students learn from their mistakes more effectively using

Section I – general information ($n = 18$)

Questions		Yes	No
1.	Is this your first experience with having homework problems graded using the concept introduced in this class?	17	1[a]
2.	Did you spend more time on doing your homework problems because of this new grading scheme?	16	2
3.	If a course adopts this new concept with homework problem submission, would you prefer to have the problems done in teams of two?	12	6
	Or would you prefer to have it done individually?	7	8[b]
4.	Should this new concept be used in all courses? If No, please list the courses that you think this new grading scheme would be beneficial (see Section III).	4	14
5.	Did you find the new concept of doing your homework problems efficient? If No, please suggest ways to improve the efficiency (see Section III).	11	5[c]

Section II – assessment of specific attributes (max. score = 5, min. score = 1)

Effectiveness in your ability to		Traditional Grading Method		The Five Whys Method	
		Average	Standard Deviation	Average	Standard Deviation
1.	Identify errors in concrete design/analysis concepts	3.72	0.90	3.67	1.09
2.	Present the assignment in professional manner	3.94	1.00	4.17	0.86
3.	Learn the concrete design concepts	3.67	0.59	3.78	0.94
4.	Learn new concrete design concepts as the quarter progresses	3.39	0.61	3.50	0.86
5.	Perform in the tests	3.56	0.92	4.00[d]	0.77
6.	Reduce recurrent errors	3.39	0.78	3.83[e]	0.92

a. The student may have misunderstood the question.
b. 2 students did not respond to this question
c. 2 students were not sure (Y/N)
d. Perform in the tests – 12.5% increase with tighter standard deviation
e. Reduce recurrent errors – 13% increase with slightly larger standard deviation

Table 1. The survey results when the Five Whys method was used for the first time during winter 2012

Section I – general information ($n = 73$)

Questions		Yes	No
1.	Is this your first experience with having homework problems graded using the concept introduced in this class?	55	18[a]
2.	Did you spend more time on doing your homework problems because of this new grading scheme?	54	19
3.	If a course adopts this new concept with homework problem submission, would you prefer to have the problems done in teams of two?	56	17
	Or would you prefer to have it done individually?	18	49[b]
4.	Should this new concept be used in all courses? If No, please list the courses that you think this new grading scheme would be beneficial (see Section III).	35	38
5.	Did you find the new concept of doing your homework problems efficient? If No, please suggest ways to improve the efficiency (see Section III).	54	16[c]

Section II – assessment of specific attributes (max. score = 5, min. score = 1)

Effectiveness in your ability to		Traditional Grading Method		The Five Whys Method	
		Average	Standard Deviation	Average	Standard Deviation
1.	Identify errors in design/analysis concepts	3.39	0.97	3.88	1.12
2.	Present the assignment in professional manner	3.91	0.92	3.93	0.89
3.	Learn the concepts	3.80	0.70	3.95	0.84
4.	Learn new concepts	3.73	0.82	3.80	0.94
5.	Perform in the tests	3.58	0.85	4.01[d]	0.87
6.	Reduce recurrent errors	3.29	0.93	3.93[e]	0.99

a. These students have taken courses using the 5 whys concept previously from the same instructor.
b. 6 students did not respond to this question
c. 3 students were not sure (Y/N)
d. Perform in the tests – 10% increase with almost identical standard deviation
e. Reduce recurrent errors – 18% increase with very close standard deviation

Table 2. The overall survey result

Effectiveness in your ability to	Traditional Grading Method		The Five Whys Method	
	Winter 2012	Fall 2015	Winter 2012	Fall 2015
1. Identify errors in design/analysis concepts	3.72/0.90	3.39/0.97	3.67/1.09	3.88/1.12
5. Perform in the tests	3.56/0.92	3.58/0.85	4.00/0.77	4.01/0.87
6. Reduce recurrent errors	3.39/0.78	3.29/0.93	3.83/0.92	3.93/0.99

Table 3. Comparison of survey results (average/standard deviation) between the first group of students (winter 2012) and the most recent group of students (fall 2015)

the Five Whys approach. Moreover, when the results of the first Five Whys implementation are compared to average results from 3 years, an improvement in students' response to question 1 [**3.88** vs. **3.29**] is detected. This change represents an increase of approximately 16% positive response on the effectiveness of Five Whys in identifying errors in design/analysis concepts. This result led the authors to further examine the students' response between the first time the Five Whys method was implemented in 2012 and the most recent implementation of the method in fall 2015. Table 3 shows the comparison of results for questions 1, 5, and 6. It is also important to note that the fall 2015 class was the first course in structural analysis, and also the first time the students were introduced to the Five Whys method. From the results shown in Table 3, it is clear that the most recent group of students found the Five Whys method to be more effective in identifying errors in design/analysis concepts than did the students in the first group. We attribute the better results to improvements made to the Five Whys template that was shared with the most recent class.
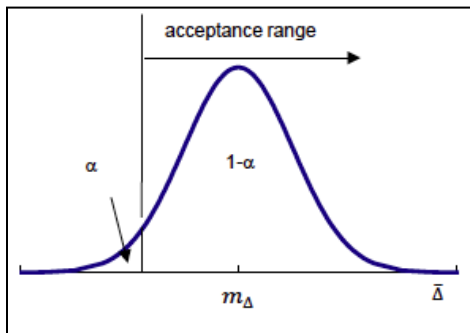

Figure 2. The one-tail acceptance range of $\overline{\Delta}$ for the hypotheses defined.

We also performed a *t statistical-test* to examine the effectiveness of the Five Whys method as it relates to the attributes 1 to 6 listed in Section II of Table 2. A simple hypothesis test was used on the difference between the effectiveness of using the Five Whys method and the traditional grading approach. Since we believe that the Five Whys method does improve the students' ability to achieve the attributes listed in Table 2, we defined the null

hypothesis H_0 as $m_\Delta \geq 0$ and the alternate hypothesis H_1 as $m_\Delta < 0$ (i.e. the Five Whys method has no impact in the student's ability to achieve the attributes). Note that m_Δ represents the true $\overline{\Delta}$ value, and $\overline{\Delta}$ is the average difference of ratings reported by the students for each question or attribute Q surveyed. Also note that the Student *t-test* was used because we do not have an established standard deviation for $\overline{\Delta}$. Figure 2 shows the acceptance range of $\overline{\Delta}$ for a given risk level a and a sample size n.

For the data collected during 2012 − 2015, we calculated the value of the standard deviation s_Δ for each attribute Q surveyed and the student response; the statistical average $\overline{\Delta}$ and s_Δ are shown in Table 4. We then determined the lower limit of the acceptance range AR, for each attribute. As shown in Figure 2, the acceptance range is all the $\overline{\Delta}$ values larger the lower limit defined by the significance level α (1- α confidence level) according to

$$AR = m_\Delta - \frac{t_{\alpha,(n-1)}s_\Delta}{\sqrt{n}} \qquad (1)$$

The results of the *t-test* for the entire population for all classes (with $n = 73$) and for the first and most recent classes in winter 2012 ($n = 18$) and fall 2015 ($n = 17$) are shown in Table 4. As an example, in winter quarter 2012, 18 students (n = 18) responded to question 1 (or attribute Q1). Moreover, the survey results yielded $\overline{\Delta} = -0.056$ and $s_\Delta = 1.662$; and from Excel, we obtained $t_{0.05,17} = 1.740$. Then using Equation (1), for the significance level of 5%, we get

$$AR = 0 - \frac{1.740(1.662)}{\sqrt{18}} = -0.681$$

Since $\overline{\Delta} \geq AR$ (see Table 4, $-0.056 \geq -0.681$, we accept the null hypothesis; that is the Five Whys method does improve the student's *ability to identify errors in design/analysis concepts* (Q1). It is clear from examining the results shown in Table 4 that we can accept the null hypothesis for all attributes for all data; from the earliest to the most recent surveys.

We now turn our attention to the results given in Table 3. As we mentioned previously, the results shown in Table 3 suggest that the students in winter 2015 class found the Five Whys method to be more effective in identifying errors in design/analysis concepts than did the students in the first group in fall 2012. We attributed the better results to improvements that we had made to the Five Whys template. We now use the *t-test* to examine this observation in more detail by changing our null hypothesis H_0 to $m_\Delta \geq a$, where a would reflect the level of improvement. For this situation, then the lower limit of acceptance range AR, Equation (1) will become

$$AR = m_\Delta - \frac{t_{\alpha,(n-1)}s_\Delta}{\sqrt{n}} = a - \frac{t_{\alpha,(n-1)}s_\Delta}{\sqrt{n}} \qquad (2)$$

Now by noting that when $\overline{\Delta} \geq AR$, we accept H_0, we can solve for the level of improvement a from Equation (2), which yields:

$$\overline{\Delta} \geq a - \frac{t_{\alpha,(n-1)}s_\Delta}{\sqrt{n}} \quad \rightarrow \quad a \leq \overline{\Delta} + \frac{t_{\alpha,(n-1)}s_\Delta}{\sqrt{n}} \qquad (3)$$

		OVERALL (all classes)		Winter 2012 - First class		Fall 2015 – Most Recent Class	
sample size, n		n = 73	accept H₀ or H₁	n = 18	accept H₀ or H₁	n = 17	accept H₀ or H₁
$t_{\alpha,n-1}$		1.666		1.740		1.746	
Q1	$\overline{\Delta}$	0.534		-0.056		0.824	
	s_Δ	1.857		1.662		2.069	
	AR	-0.362	accept H₀	-0.681	accept H₀	-0.876	accept H₀
Q2	$\overline{\Delta}$	0.014		0.222		0.000	
	s_Δ	1.007		1.166		0.791	
	AR	-0.196	accept H₀	-0.478	accept H₀	-0.335	accept H₀
Q3	$\overline{\Delta}$	0.219		0.111		0.471	
	s_Δ	1.170		1.278		1.281	
	AR	-0.228	accept H₀	-0.524	accept H₀	-0.542	accept H₀
Q4	$\overline{\Delta}$	0.137		0.111		0.353	
	s_Δ	1.134		0.900		1.455	
	AR	-0.221	accept H₀	-0.369	accept H₀	-0.616	accept H₀
Q5	$\overline{\Delta}$	0.370		0.444		0.647	
	s_Δ	1.253		1.247		1.115	
	AR	-0.244	accept H₀	-0.511	accept H₀	-0.472	accept H₀
Q6	$\overline{\Delta}$	0.685		0.444		0.765	
	s_Δ	1.649		1.247		1.480	
	AR	-0.322	accept H₀	-0.511	accept H₀	-0.627	accept H₀

Notes:
Q1: Effectiveness in your ability to identify errors in design/analysis concepts
Q2: Effectiveness in your ability to present the assignment in professional manner
Q3: Effectiveness in your ability to learn the concepts
Q4: Effectiveness in your ability to learn new concepts
Q5: Effectiveness in your ability to perform in the tests
Q6: Effectiveness in your ability to reduce recurrent errors
accept H₀ implies Five Whys method is more effective than traditional method

Table 4. Results of hypothesis tests for data collected from Winter 2012 to Fall 2015

Effectiveness in your ability to		W2012	F2015
	n	18	17
	$t_{\alpha,(n-1)}$	1.740	1.746
Q1. Identify errors in design/analysis concepts	$\bar{\Delta}$	-0.056	0.824
	s_{Δ}	1.662	2.069
	a	0.625	1.70
Q5. Perform in the tests	$\bar{\Delta}$	0.444	0.647
	s_{Δ}	1.247	1.115
	a	0.955	1.119
Q6. Reduce recurrent errors	$\bar{\Delta}$	0.444	0.765
	s_{Δ}	1.247	1.480
	a	0.955	1.392

Table 5. The comparison of the level of improvement a between the winter 2012 and fall 2015 classes

Using Equation (3), the *a* values for the attributes given in Table 3 were then computed. The results of this analysis are shown in Table 5. When examining Table 5 note that the *a* values are higher for the winter 2015 class than the *a* values for the fall 2012 class, confirming our observation that improvements were made in the Five Whys template.

Let us now turn our attention to the results of the interviews. As mentioned previously, 63 students who completed the Five Whys survey forms, also met with a researcher from the Northwestern University Searle Center for Advancing Learning and Teaching and provided additional feedback. After discussing a question in small groups and then collectively, all students came to a consensus on the aspects that they had agreed were most important. Each participant (student) then indicated on a scale of 1 to 9 (1 = strongly disagree, 9 = strongly agree) to the extent that he or she agreed that this aspect of the Five Whys enhanced his or her own learning. This approach gave every student a chance to voice his or her own opinion. During this process, students collectively identified two aspects of course that they felt enhance their learning. These aspects are shown in Table 6. As shown in Table 6, a majority of students found working with partners and using the Five Whys helped them learn more efficiently.

Students' Comments – Comments made by the students in the survey forms and during the interviews can be grouped into different broad categories including (1) Five Whys effectiveness, (2) partner participation, (3) time commitment, and (4) the tendency to stop at symptoms.

1. Many students found the Five Whys method to be effective, particularly when it comes to averting recurring mistakes.
2. Many students also cited the importance of having a good partner for this approach to be effective. Some felt that their partners did not contribute as much by asking proper questions, because of the lack of effort and interest in the course;
3. There was also concern about the time commitment required for this method to be effective.
4. The tendency of students to stop at symptoms and not to proceed to the root cause was also evident from analyzing the students' comments.

Examples of students' comments are shown below to give the reader an idea of what the students said in their own words about the Five Whys method.

- "I really like this method [Five Whys] but I feel like it highly depends on whether your partner and you are both at the same level. I've seen few other teams where only one team member would be doing the assignment because the other team member just doesn't try to do them or where the team members couldn't find a time that works out for the two to meet. I don't know how it would be possible to choose a compatible team all the time, but I do believe that that is the driving force to make this method work."

- "I guess the only problem of the self-learning method [Five Whys] has to do with who you are working with. If the members of the team do not put the same effort/interest in the course, the work load can be very painful. However, if this is not the case, then then self-learning method can be much more efficient."

- "I think if the homework is to be done on groups, there should be a group evaluation at the end of the quarter in order to ensure that each member is contributing to the homework, It isn't fair to have one person do all of the work while the other still gets credit for it. While it becomes obvious if this is happening during test time, it still would be nice to have that extra assurance that someone cannot take credit for someone else's work."

- "Doing homework in two rounds had us to focus on learning the concepts and really trying to do the homework of our own effort and not seek quick advice on how to get the right answer. Because I knew that there was no pressure of getting a grade the first time, I attempted the homework as a learning tool where it is okay to learn from our mistakes. The traditional homework system does not allow for this -- it penalizes mistakes that then affect your overall grade. That does not encourage learning -- that encourages trying to get the right answer (which does not always result in understanding and learning). Also, working with a partner was really helpful because it let us discuss the homework while doing it. I personally learn and figure things out much better when I talk to someone about it, even if I am doing all the talking -- it helps organize my thoughts. This sort of constant necessary discussion about each homework assignment was therefore very helpful to learning."

- "I really liked the new homework system [Five Whys]. My only issue with it is that sometimes the comments were very unclear as to what was wrong and why it was wrong. Perhaps slightly more in depth comments on the first draft would help fix this and make it more clear."

- "Partners are very important for this type of HW submission. It helps a lot to have someone to discuss the errors with. In some cases, more clarity from the instructor with comments could be beneficial."

- "more feedback needed in order for this method [Five Whys] to be better than the traditional method. As mentioned above, more feedback would help as well as solutions for the homework after they are due."

- "While the two submissions method allowed self-improvement and better understanding, it resulted in working on the homework almost every night of the week which was, at times, too much. Also, providing clearer comments on where we errored would have been useful. I benefitted greatly from the collaboration between me and my partner."

Question	Result
Working with partners and using the "Five Whys" help learn more efficiently	Average: 7.89 83 % Agree 17 % Neutral
The resubmissions policy used with the "Five Whys" for homework is very helpful	Average: 7.61 81% Agree 19% Neutral

Table 6. The result of interview (1 = strongly disagree, 9 = strongly agree)

- "The new scheme [Five Whys] is great, helped working with another student so we can fix each other's mistakes."

- "Having the homework submitted in two rounds significantly reduced the pressure of the class and allowed a more relaxed learning environment. This does not mean that less time was spent on the homework or that it was taken less seriously- it is simple changed the psychology behind it. It allowed us to focus on learning the concepts and honestly attempting the assignments rather than simply asking someone for help while not really understanding it in order to meet a due date and get the right grade. Moreover, we were able to discuss the homework since it pushed us to collaborate with one another, which was good because I feel that conversation and explaining your thought process to someone significantly improves learning. Overall, I think this is a very good way of turning the homework into a learning tool that gets rewarded with a grade rather than a one-shot assignment that can be stressful to tackle."

- "I understand that the point of the self-learning [Five Whys] method is to have us identify the mistakes we made. However a little more feedback would be very helpful. All we got were "x"s indicating the final number/answer is incorrect at the end of a section."

- "I really like having this new method [Five Whys] of doing homework. I feel like I got more out of each assignment because this method forces you to go back and figure out what you did wrong and think about how you can prevent it in the future, instead of turning it in and just forgetting about it."

- "The current method is very time consuming and allows for people to rely greatly on their partners if they were to not have a good group. This course would make it very hard on an individual to do every week for all classes."

- "It definitely does take more time to do it this way so the professor should keep that in mind and perhaps assign less. It did make us recognize our errors which helped a lot. Often students just glance over homework that is returned so this method helped and prevents that. In terms of doing it in partners I think it really depends on your partner so it hard to say."

- "It sometimes becomes very difficult to keep that pace that the quarter system demands with this new approach [Five Whys] due to time constraints. However, I do believe this new method is much more beneficial for the student's broader understanding of the general concepts, which is key in a class such as concrete design."

- "I think this method works well with courses that have a lot of mathematical and methodical assignments. I'm not sure that this same method would

work quite as well if this was a seminar-based course or it required other peer-lead structures."

- "I think it is one of the best homework-concepts around, as it allows you to learn from your mistakes rather than just getting things wrong. I would love to have it in other courses."

Conclusion – The benefits and challenges of using the Five Whys

The survey and the interview results suggest that overall students found the Five Whys method to be effective in identifying errors in design/analysis concepts and in averting recurring mistakes; present the assignment in professional manner; learn new concepts; and perform better in tests. Many students believed that they got more out of each assignment, in terms of understanding new concepts, because the Five Whys approach forced them to go back and figure out what they did wrong and think carefully about how to avoid the mistake from recurring. As is the case with any new educational tool, challenges have been identified that must be addressed in the future. Many students cited the importance of having a good partner with interest in the course subject matter who would contribute to the Five Whys process by asking proper questions. The Five Whys method also compelled students to spend more time on the assignment, as the result, there was concern about the time commitment required for this method to be effective. The tendency of students to stop at symptoms and not to proceed to the root cause is also a concern. This tendency could be attributed to the lack of a facilitator beyond the instructor to help students to ask the right questions. This deficiency could result in different students with similar problems come up with a different root cause. The authors are planning to collaborate with the Northwestern University Searle Center for Advancing Learning and Teaching to apply the lessons learned from this study to refine the Five Whys method to create a universal template that could be used by instructors in all engineering courses across the U.S. and abroad. In addition, we are preparing to create a Facebook community for the Five Whys population to interact. We also intend to monitor and analyze the Facebook traffic and the interactions to improve the effectiveness of this unique approach. These plans are contingent upon availability of funds through a currently pending NSF proposal.

References

[1] Yan, S. "Understanding Generation Y" http://www.oberlin.edu/stupub/ocreview/2006/12/08/features/Understanding_Generation_Y.html

[2] Junco, R. and Mastrodicasa, J. (2007)," Connecting to the Net Generation: What Higher Education Professionals Need to Know About Today's Students," NASPA.

[3] M. Loving and M. Ochoa (2011), "Facebook as a classroom management solution," New Library World, Vol. 112 -3/4, pp.121 – 130.

[4] Kelly Walsh (2012), "Can Social Media Play a Role in Improving Retention in Higher Education? Research Says it Can," Emerging Ed Tech, October 28, 2012 Issue.

[5] Avi Wolfman-Arent (2014), "Why This Professor is Encouraging Facebook Use in His Classroom", the Chronicle of Higher Education, August 5, 2014 Issue.

[6] Bransford, J.D. (1979) Human Cognition: Learning, Understanding, and Remembering, Wadsworth, CA.

[7] Bransford, J.D., Stein, B.S., Vye, N.J., Franks, J.J., Auble, P.M., Mezynski, K.J., and Perfetto, G.A. (1983) "Differences in Approaches to Learning: An Overview," Journal of Experimental Psychology: General. Vol. 3, No. 4, pp. 390-398.

[8] Broudy, H.S. (1977), "Types of Knowledge and Purposes in Education," Schooling and the Acquisition of Knowledge, R.C. Anderson, R.J. Spiro, and W.E. Montague (Eds.), Erlbaum, NJ.

[9] Byrnes, J.P. (1996) Cognitive Development and Learning in Instructional Contexts, and Bacon, Boston.

[10] Chi, M.T.H., Bassok, M., Lewis, N.W., Reimann, P. , and Glaser, R. (1989) "Self-Explanations: How Students Study and Use Examples in Learning to Solve Problems," Cognitive Science, Vol. 13, pp. 145-182.

[11] Chi, M.T.H., deLeeuw, N., Chiu, M., and LaVancher, C. (1994) "Eliciting Self-Explanations Improves Understanding," Cognitive Science, Vol. 18, pp. 439-477.

[12] Luchins, A.S. and Luchins, E.H. (1970) Werbeimer's Seminar Revisited: Problem Solving and Thinking, Vol. 1, State University of New York Press, Albany, NY.

[13] Singley, K. and Anderson, J.R. (1989) The Transfer of Cognitive Skill, Harvard University Press, MA.

[14] Bransford, J.D., Brown, A.L., and Cocking, R.R. (eds.). (2000) How People Learn: Brain, Mind, Experience, and School, Expanded Edition, National Academy Press.

[15] Klausmeier, H.J. (1985) Education Psychology, 5th ed., Harper and Row, New York.

[16] Gick, M.L. and Holyoak, K.J. (1983) "Sch. Induction and Analogical Transfer," Cognitive Psychology, Vol. 15, pp. 1-38.

[17] Vanden Heuvel, L.N., Lorezno, D.K., Montgomery, R. L., Hanson, W.E., and Rooney, J.R., Root Cause Analysis Handbook: A Guide to Efficient and Effective Incident Investigation, 3rd Edition, 2008, Rothstein Associates, Inc.

[18] Okes, Duke, Root Cause Analysis: The Core of Problem Solving and Corrective Action, 2009, Quality Press.

[19] Serrat, Oliver, The Five Whys Technique, 2009, Knowledge Solutions.

[20] Ohno, Taiichi, Ask Whys Five Times About Every Matter, 2006, Toyota Motor Corporation.

Saeed Moaveni is currently Professor of Mechanical Engineering at Minnesota State University, Mankato. Dr. Moaveni has nearly 30 years of experience in teaching and research in mechanical and civil engineering related areas. Professor Moaveni also has served as Dean of the David Crawford School of Engineering at Norwich University and Chair of the Mechanical and Civil Engineering Department at Minnesota State University. He is a licensed Professional Engineer (PE) in the State of New York, and a member of various engineering societies.

Dr. Karen C. Chou is Assistant Chair and Clinical Professor of Civil and Environmental Engineering at Northwestern University. She is a Fellow of ASCE and a registered Professional Engineer in six states. Dr. Chou has 35 years of academic and engineering experience. She was recognized numerous times by the American Society of Civil Engineers (ASCE) for her excellent service to the student chapters. Dr. Chou received the Charles W. Britzius Distinguished Engineer Award from the Minnesota Federation of Engineering, Science, and Technology Societies and the Civil Engineer of the Year from the Illinois Section ASCE.