AC 2008-2223: A MULTIDISCIPLINARY ENVIRONMENT FOR COOPERATIVE LEARNING USING DESIGN OF EXPERIMENTS AND POLYMER PROCESSING

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Abstract

The Advanced Quality Control class in the Industrial Engineering Department at Kettering University has taken a unique approach to practical learning by turning the course into a multidisciplinary effort with the Mechanical Engineering Polymer Processing course. Building on the knowledge developed in prerequisite courses, the IE student will use tools in Statistical Process Control (SPC), Design of Experiments (DoE), and Response Surface Methodology (RSM) to characterize and optimize the process of injection molding of plastics. The mechanical engineering students will better understand the significant effect of certain factors (parameters) on the quality of injection molded parts by using the statistical tools available. In this paper, we will discuss how this group of students interact and gain knowledge and skills through teamwork. We will also discuss how integration of the two engineering disciplines using DoE and polymer processing provides the students with the experience of the real-world work environment.

Introduction

At a time when the working world is constantly changing and advancing, schools must also change and advance to ensure that they are providing their students with the most up-to-date education possible. We are no longer in a time where simulated examples and case studies will suffice. Students need real, practical learning environments where they uncover and solve the problem together. They need to experience in the classroom the same unexpected problems and difficulties that they will face in the real working world and the team dynamic necessary to resolve them. It is in dealing with these unexpected problems that students really begin to develop the capability to meet future challenges. According to Susan Prescott, “Employers report that their biggest problems center around the inability of people to interact productively. Students need to hear that class groupwork is valuable preparation for future problem solving in team settings in the work place as well as an opportunity to more effectively learn the course curriculum[1].” By providing students with a student-driven, multidisciplinary experience, they gain independence and confidence in their ability to apply what they have learned to solve problems that cannot be found in a textbook or case study, problems that they face today and problems that they have yet to discover

To give students this type of experience, Kettering University has embarked on a path of multidisciplinary learning. We have created a learning environment where the students are the driving force for the class, where industrial engineering students teach mechanical engineering students and mechanical engineering students teach industrial engineering students. In the class, students can look to each other for answers and broaden their understanding of engineering knowledge and skills. They are beginning to realize that they have a wonderful asset at their immediate disposal and opportunities to learn from each other. By having industrial engineering and mechanical engineering students in one classroom, they can now see firsthand how the knowledge obtained in their disciplines can be applied to other areas of engineering. This creates a much more satisfying learning environment by allowing them to explore their curiosity and try to solve real-world problems that they uncover in collaboration with their peers. When students deal with a problem from its conception to its resolution, it can be more gratifying and is truly an unparalleled learning experience. Again, Prescott notes that, "The more the students invest in their own learning process, the more they will learn. Cooperative learning offers a natural method by which students can become successfully empowered in the classroom.[1]" These sentiments were shared by students of Kettering University when the Polymer Processing class of the Mechanical Engineering Department and the Advanced Quality Assurance class of the Industrial Engineering Department combined efforts in the summer of 2007.

Integration of Two Industrial Engineering and Mechanical Engineering Courses

In the summer of 2007, an industrial engineering (IE) student armed with understanding of statistical process control (SPC), design of experiments (DoE), gage repeatability and reproducibility (R&R) and response surface methodology (RSM) from the Advanced Quality Assurance class served as a quality assurance consultant for four mechanical engineering (ME) students of the Polymer Processing class. The ME students were seeking a better understanding of the variables that affect the quality of plastic parts produced on an injection molding machine. They were looking for improvement of their product and to learn the tools necessary to fully characterize the process. The IE student was looking for a practical application of the tools he had been using in the Advanced Quality Assurance class and a better understanding the basics of polymer processing. To achieve this, the IE student was side-by-side with the ME students from the beginning of the course learning the basics of polymer material properties and basic injection molding machine operation. The IE student was familiarized with the pertinent factors (variables, parameters) that affect the quality of an injection molded part and he learned the process that he would be investigating in the lab. A full understanding of the basics of polymer process was required by the IE student before he could proceed working with the ME students.

Design of Experiments (DoE) is an important tool that deals with process improvement. The basic DoE concepts were introduced to the ME students. After the basics of polymer processing were covered, the ME students began designing and conducting their experiments with the help of the IE student. Prior to any experiment, the ME students would discuss what factors (variables, parameters) might have an impact on the injection molding process with the IE student and, in-turn, the IE student would recommend the appropriate experimental design to meet the needs of the ME students. In addition to designing experiments, the IE student was also available during the experiments to answer questions in regards to testing procedure or to explain why a certain design was being used. Once the experiment and testing was complete, the IE student took the gathered data and analyzed it. The results of each experiment were then interpreted and discussed with the ME students in light of the findings. The ME students were not just provided with a report indicating the findings; they were taught how to analyze the data themselves and to obtain the same result using statistical software like MINITAB®[2]. Experiments like these were conducted for the duration of the course with great emphasis on collaboration and the ability to be self-sufficient in the future. Once the course was complete, each student could take what they had learned and apply it to future situations.

A Design of Experiments Project

This section provides a representative experiment for polypropylene plastic conducted by the IE and ME students and demonstrates how the multidisciplinary team dynamic worked. At first, the ME students were most interested in fully understanding what machine factors (parameters) affected part quality. Then the ME students developed a list of the various quality characteristics that they were most interested in investigating. These quality characteristics included properties like mass, part shrinkage, max load of part (part strength), and part toughness. Based upon historical data, the ME students then selected the machine factors that they believed would have an effect upon the selected quality characteristics. To determine various levels (values) of the machine factors, the ME students communicated historical data to the IE student, who then advised the ME students to pick a low and a high value for each factor to accommodate a 2^k full factorial experimental. The IE student chose a 2^k design with k representing the number of factors, because it provided the most efficient method of screening for significant factors. A table of the factors and levels chosen for this experiment can be seen in Table 1. Once the appropriate range was selected, the IE student developed a worksheet for the ME students to use when running the experiment. The worksheets were developed using MINITAB®[2] software and provided the ME students with a fully randomized run order.

Table 1. Factor Table with Levels

Factor	*Low*	*High*
Mold Temp (°F)	95	120
Cooling Time (sec)	20	40
Pack Time (sec)	0.5	7.5
Pressure (psi)	100	350

To test each quality characteristic, the ME students produced tensile bars on the injection molders at the various levels and in the order developed by the IE student. Then, the ME students measured each part to establish a response (measurement value) for the varying levels of the experiment. After all of the data was collected, the IE student began his analysis. Using MINITAB®[2] software, the IE student conducted a comprehensive analysis on the data considering all possible interaction of factors. Using analysis of variance (ANOVA) tables in conjunction with p-value tables, the IE student generated reports indicating which machine factors, had a significant impact on the selected quality characteristics. Figure 1 is an example of the ANOVA table generated for shrinkage and Figure 2 shows the accompanying p-value table. The ANOVA table indicates that three main effects and one interaction effect had a significant effect on the shrinkage of the tensile bar. After referring to the p-value table, it was determined that cooling time, pack time, and pressure all had a significant effect on the shrinkage of the tensile bar. In addition, the p-value table indicated that the interaction of cooling time and pack time also had a significant impact on shrinkage of the tensile bar. When interaction is present, it takes precedence over the main effect of the factors involved because the factors can no longer be considered independently. Thus, only the interaction of cooling time with pack time and the main effect of pressure were considered.

```
Analysis of Variance for Shrinkage (in), using Adjusted SS for Tests

Source                          DF     Seq SS     Adj SS     Adj MS
Blocks                           2  0.0002341  0.0002341  0.0001171
Mold Temp                        1  0.0000002  0.0000002  0.0000002
Cooling Time                     1  0.0047402  0.0047402  0.0047402
Pack Time                        1  0.0150167  0.0150167  0.0150167
Pressure                         1  0.0018625  0.0018625  0.0018625
Blocks*Mold Temp                 2  0.0000691  0.0000691  0.0000346
Blocks*Cooling Time              2  0.0001321  0.0001321  0.0000661
Blocks*Pack Time                 2  0.0001591  0.0001591  0.0000796
Blocks*Pressure                  2  0.0001970  0.0001970  0.0000985
Mold Temp*Cooling Time           1  0.0000935  0.0000935  0.0000935
Mold Temp*Pack Time              1  0.0001172  0.0001172  0.0001172
Mold Temp*Pressure               1  0.0000500  0.0000500  0.0000500
Cooling Time*Pack Time           1  0.0009630  0.0009630  0.0009630
Cooling Time*Pressure            1  0.0000005  0.0000005  0.0000005
Pack Time*Pressure               1  0.0000285  0.0000285  0.0000285
```

Figure 1. ANOVA Table for Part Shrinkage

```
Source                                  F       P
Blocks                               2.42   0.933
Mold Temp                            0.01   0.948
Cooling Time                        71.75   0.014
Pack Time                          188.74   0.005
Pressure                            18.90   0.049
Blocks*Mold Temp                     0.27   0.838
Blocks*Cooling Time                  3.44   0.972
Blocks*Pack Time                       **
Blocks*Pressure                      0.69   0.776
Mold Temp*Cooling Time               3.24   0.214
Mold Temp*Pack Time                  2.60   0.248
Mold Temp*Pressure                   0.23   0.677
Cooling Time*Pack Time              11.94   0.075
Cooling Time*Pressure                0.00   0.960
Pack Time*Pressure                   0.40   0.590
```

Figure 2. P-Value Table for Shrinkage

These same results were shared with the ME students, and their meanings were explained fully so that the ME students could understand this type of data analysis in the future. Once the significant factors were determined, it was then necessary to see how the significant factors affected the quality characteristics. To do this, effects plots were generated by the IE student in MINITAB®[2] and shared with the ME students. An example of effects plots for shrinkage can be found in Figures 3 and 4 on the next page. For these plots, a high value represents a favorable result as length of the part was measured, meaning that the greater the length, the less shrinkage of the part. From these plots, it was determined that a high pressure was desirable to minimize part shrinkage. In addition, a high cooling time coupled with a high pack time was most desirable to minimize part shrinkage. The IE student fully explained to the ME students the proper method for interpreting these plots so that they had a basic understanding if they encountered the same analysis in the future.

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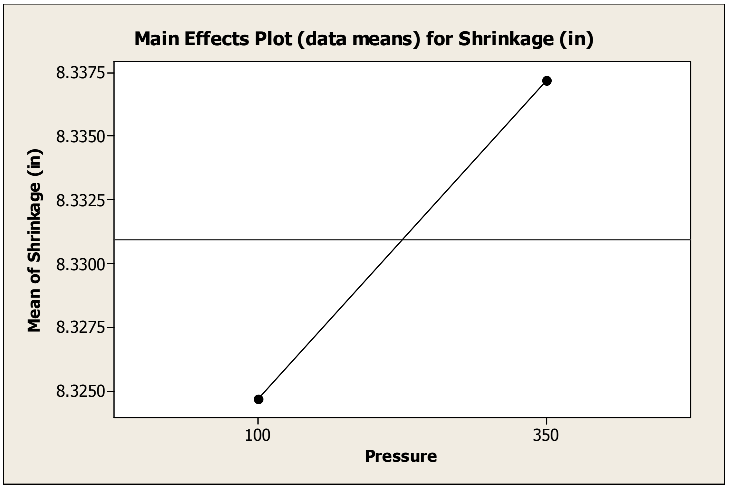

Figure 3. Main Effects Plot for Pressure on Part Shrinkage (Length)

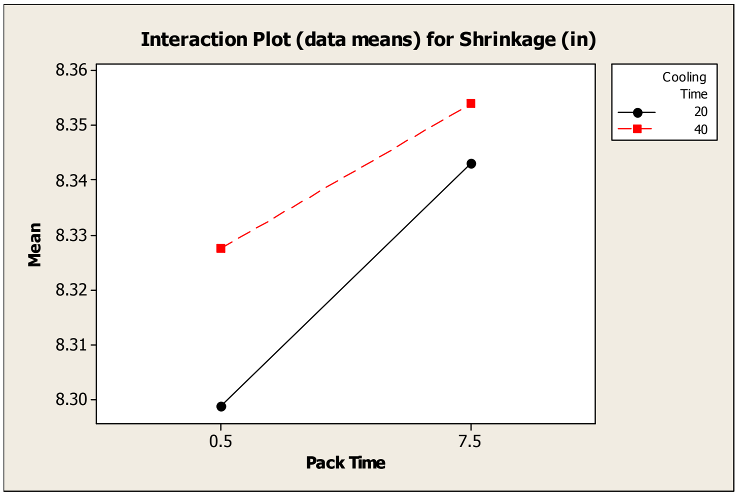

Figure 4. Interaction Plot of Cooling Time and Pack Time on Part Shrinkage (Length)

Team Dynamic, Evaluation Process for the Multidisciplinary Teams

Since neither the IE student nor the ME students had much exposure to the field of study of the other, team work became the focus of the learning experience. This required greater cooperation and communication between each discipline. This was achieved by meetings twice a week with discussions about future experiments, experimental results, and interpretation of results. These meetings were very open, with the students being the primary contributors. It was during these meetings that the greatest learning took place. Ideas and questions were exchanged freely. The students discussed the problems and obtained the answers together. This resulted in a more comfortable learning environment with communication continuing outside of class via e-mail. Evidence of this can be found in the Self-Assessment Worksheet Data in Figure 5. On average, the team members rated their comfort level (statement number one of teamwork self-assessment worksheet) at the highest rating possible. In addition, the team members rated their participation, listening, and praise (statements two through four of the teamwork self-assessment worksheet) equally high. The team dynamic really helped the students to develop their communication skills with emphasis on communication with those who may not understand their specific field of study. It also helped to develop the capacity to collaborate with others to fully understand a process and solve associated problems. This is indicated by the highest possible ratings by the students for statements five and six of the teamwork self-assessment worksheet, which rate the students' contribution to others who did not understand something and their willingness to ask for explanations when they themselves did not understand. An example of the teamwork self-assessment worksheet can be found in the Appendix.

When multiple disciplines cross paths, some challenges can arise. In the class, each discipline can have different objectives for what it hopes to achieve and at times, those objectives can create conflict. For example, the ME students wanted to cover more advanced polymer processing techniques, while the IE student was more interested in applying advanced tools such as RSM for process improvement. However, the time constraints on both classes can limit the coverage of the course materials and thus clearly defined objectives are vital to ensuring that each group gets the most out of the available time. According to Robert F. Mager, "Clearly defined objectives can be used to provide students with the means to organize their own time and efforts toward accomplishment of those objectives[3]." For this reason, it is important to set the objectives for the team project early in the process and perform periodic checks to make sure the team is meeting those objectives. All team members should make and agree on a plan at the beginning of the project so everyone understands the expected outcomes for the group and what they will gain personally from the experience.

The best way to measure adherence to the original goals, and gauge each member's perception of the team and remedy potential problems is to conduct surveys periodically throughout the term. John E. Travis notes that; "Faculty need input from students during the process of instruction to discover the problems students might be having with learning while difficulties can still be corrected[4]." In this case, surveys were done every two weeks starting with the second week of the term. These surveys had questions evaluating how the individual thought the project itself was going and some questions to weigh his/her involvement and satisfaction with the team in the previous two weeks. There was also a final survey given at the end of the class to measure the overall effectiveness of the multi-disciplinary team structure for learning. Detailed survey data were collected and the results were shown in Figure 5. The sample copies of the survey forms used are included in the Appendix[5]. From the data, we can see that all team members gave consistently high marks for this learning experience throughout the term and at the end of the term.

		Self-Assessment Worksheet														Team Evaluation Worksheet				
		Felt comfortable working…	Was an active…	Listened to everyone…	Encouraged and praised…	Explained/helped someone…	Asked for an explanation…	Felt encouraged…	Felt comfortable…	Found the team…	Believe my team…	Effective use of time	Development of ideas	Ability to decide issues	Overall Productivity					
Name	Week	1	2	3	4	5	6	7	8	9	10	1	2	3	4	Student 1	Student 2	Student 3	Student 4	Student 5
Student 1	10	3	3	3	2	3	3	2	3	3	2	6	5	5	6	20	22	21	19	18
Student 2	10	3	3	3	3	2	3	3	3	3	3	6	5	6	6	18	25	20	18	18
Student 3	10	3	3	2	3	3	3	3	3	3	3	6	6	5	6	20	20	20	20	20
Student 4	10	3	3	3	3	3	3	3	3	3	3	7	7	7	7	20	20	20	20	20
Student 5	10	3	3	3	2	3	3	3	3	3	2	6	6	6	6	20	20	20	20	20
Student 1	8	3	2	3	3	3	3	3	2	3	3	6	6	7	6	20	20	20	20	20
Student 2	8	3	3	3	3	2	2	3	3	3	3	6	5	6	6	20	20	20	20	20
Student 3	8	3	3	3	3	3	3	3	3	3	3	7	7	7	7	20	20	20	20	20
Student 4	8	3	3	3	3	3	3	3	3	3	3	7	6	6	7	20	20	20	20	20
Student 5	8	3	3	2	3	3	2	3	3	3	3	6	6	6	5	20	20	20	20	20
Student 1	6	2	3	3	3	2	1	2	2	2	2	6	6	5	6	22	22	22	18	16
Student 2	6	3	3	3	3	3	3	3	3	3	3	6	6	6	6	20	20	20	20	20
Student 3	6	3	0	3	3	3	3	3	3	3	3	6	7	6	6	25	25	0	25	25
Student 4	6																			
Student 5	6	3	3	3	2	3	3	3	3	3	3	6	6	6	6	19	19	24	19	18
Student 1	4	2	3	2	2	3	2	1	2	2	3	5	6	6	6	20	21	21	19	19
Student 2	4	3	3	3	3	3	3	3	3	3	3	6	7	6	7	20	20	20	20	20
Student 3	4	3	3	3	3	3	3	3	3	3	3	7	7	7	7	20	20	20	20	20
Student 4	4	2	3	3	3	3	3	2	3	3	3	6	6	6	6	20	20	19	21	20
Student 5	4	3	3	3	3	3	3	3	3	3	3	7	7	7	7	20	20	20	20	20
Student 1	2	3	3	3	2	2	3	3	3	2	2	6	6	4	5	18	18	20	17	17
Student 2	2	3	3	3	3	2	2	2	3	2	3	5	5	5	6	20	20	20	20	20
Student 3	2	3	3	3	3	3	3	2	3	3	3	5	6	7	5	20	20	20	20	20
Student 4	2	3	3	2	2	2	2	2	2	3	3	6	6	7	7	20	20	20	20	20
Student 5	2	3	3	3	3	2	2	3	3	2	3	6	6	6	6	20	20	20	20	20
Average		3	3	3	3	3	3	3	3	3	3	6	6	6	6	20	21	19	20	20

Figure 5. Self-Assessment Worksheet Data

The Accreditation Board for Engineering and Technology (ABET), Inc. engineering accreditation criterion 3 has specific Program Outcomes (POs) for the engineering disciplines[6]. The multidisciplinary approach to teaching and learning relates directly to Program Outcome D: the graduates have an ability to function on multidisciplinary teams. Teamwork is often emphasized in engineering courses, but it is often within a single class or discipline. By integrating the Advanced Quality Assurance class with the Polymer Processing class, the students are able to gain valuable experience working in multidisciplinary teams much like they will encounter when they begin their professional careers. The ability to function effectively in multidisciplinary teams is an important attribute and asset for graduating engineers because most problem-solving methodologies in the industry require multidisciplinary teamwork. The success of achieving program outcome D can be seen from the team survey results in Figure 6.

		Statements for ranking											
		Attends group meetings…	Initiate and maintins…	Works for constructive…	Strives for meaningful…	Supports other team…	Initiates and participates…	Worked to define…	Collected/Provided data…	Worked to generate…	Worked to document…	Effectiveness in performing..	Listening and speaking…
Team Member	Your Name	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	3.1	4.1
All	Student 1	3	3	3	3	3	3	3	3	3	3	3	3
Student 1	Student 2	3	3	3	3	3	3	3	3	3	3	3	3
Student 1	Student 3	3	2	3	3	3	3	3	2	2	3	3	3
Student 1	Student 4	3	3	3	3	3	3	3	3	3	3	3	3
Student 1	Student 5	3	3	3	3	3	3	3	3	3	3	3	3
		3	2.8	3	3	3	3	3	2.8	2.8	3	3	3

Figure 6. ABET Program Outcome D Class Survey Results

We also looked at the other ABET engineering program outcomes that are pertinent to this project. Program Outcomes B, E, and G are discussed here. Program Outcome B is the graduate's ability to design and conduct experiments, as well as to analyze and interpret data. This is an outcome that the IE student was most able to teach to the ME students as ME students are often not exposed to proper experimental techniques. The interaction between the two disciplines allows the students to teach and learn from each other to meet the expected program outcomes. The industrial engineering student designs the experiments, analyzes the data, and reports the results while the mechanical engineering students conduct the experiment and gather the data. The IE student then shared the results and the associated analytical procedure with the ME students so that they could be self-sufficient in the future.

Program Outcome E is the graduate's ability to identify, formulate, and solve engineering problems. In reference to Outcome B, the ME students are generally stronger in Outcome E than the IE student. The ME students are more familiar with the product and the associated factors (variables, parameters) that affect product quality and therefore can identify problems more readily. By interacting with the ME students and communicating openly about the problems and possible factors they wanted to investigate and why they wanted to investigate them, the IE student gained a better understanding of the problem identification process and how mechanical engineers approach a problem.

Program Outcome G is the graduate's ability to communicate effectively. This PO was developed through weekly lab reports and presentations. The students worked on the lab reports together and presented their findings to the rest of the class. The most notable communication skill developed was communication with another engineering field. The students experienced firsthand the difficulty of explaining unfamiliar concepts. They learned what technical information to include and what to exclude to explain the pertinent information as efficiently as possible.

Conclusion

Multidisciplinary teams provide unique opportunities for working with different engineering disciplines. With multidisciplinary teamwork, team members bring with them their respective knowledge, skills and experiences for the betterment of the group. In this project, we combined the strengths of each field of expertise and were able to have a more meaningful project outcome. We learned new skills in the process, skills that we can take with us to our jobs. Kettering University has seen the benefits of multidisciplinary learning firsthand. Not only did students learn more about another discipline's field, they learned how to communicate and collaborate collectively to find solutions to problems. The project used problems that could not be found in a textbook. This real world learning environment provided an unparalleled experience for all involved.

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Appendix

Team Evaluation Worksheet

Team Name:

Your Name ______________________Date:

For each of the items below, circle the number that best represents your evaluation of the ***entire*** team's performance.

Effective Use of Time

7	6	5	4	3	2	1
No wasted effort; stayed on target		Did well once we got our ideas clear		Got off track frequently		Much time spent without purpose

Development of Ideas

7	6	5	4	3	2	1
Ideas encouraged and explored		Friendly session but not creative		Ideas imposed by a few		Little done to generate ideas

Ability to Decide Issues

7	6	5	4	3	2	1
Genuine agreement and support		Made compromises to get the job done		Let one person rule		No resolution of differences

Overall Productivity

7	6	5	4	3	2	1
Highly productive session		Just did what we had to do		Barely finished the job		Did not reach our goal

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In the space below, list the names of your team members (including yourself) and **allocate 100 points** to the team based on your opinion of individual performance. The sum of all points allocated should equal 100. Be sure to give yourself an appropriate number of points as well.

Team Member	Points
1.	
2. ________________________________	_____________
3.	
4. ________________________________	_____________
5.	

Suggestions and comments for improvement of team performance:

Teamwork Self-Assessment Worksheet

Team Name:____________________ **Your Name**________________ **Date:** _________

Read each statement below, and then circle the number that best represents your experience as a team member.

(3 = Agree completely, 2 = Agree somewhat, 1 = Disagree somewhat, 0 = Completely disagree)

1.	I felt comfortable working with this team	3	2	1	0
2.	I was an active participant in my team	3	2	1	0
3.	I listened to everyone on my team	3	2	1	0
4.	I encouraged and praised others on my team	3	2	1	0
5.	I explained/helped someone who didn't understand	3	2	1	0
6.	I asked for an explanation or help when I didn't understand	3	2	1	0
7.	I felt encouraged by people on my team	3	2	1	0
8.	I felt comfortable in my role as __________________	3	2	1	0
9.	I found the team activities to be a worthwhile experience	3	2	1	0
10.	I believe that my team working skills improved in this course	3	2	1	0

Specific ideas for improving my own performance on this and other teams:

Suggestions that would improve the team's performance in general:

End-of-Term Peer Teamwork Evaluation Worksheet

Team Member's Name:__________________________________Date: ____________

Read each statement below and then circle the number that best represents your evaluation of your teammate's performance.

(3 = Agree completely, 2 = Agree somewhat, 1 = Disagree somewhat, 0 = Disagree completely)

1. **Team Participation**

• Attends group meetings on regular basis	3	2	1	0
• Initiates and maintains task-oriented dialogue	3	2	1	0
• Works for constructive conflict resolution	3	2	1	0
• Strives for meaningful group consensus	3	2	1	0
• Supports other team members	3	2	1	0
• Initiates and participates in group maintenance	3	2	1	0

2. **Assignment Completion**

• Worked to define problem	3	2	1	0
• Collected/provided data relevant to problem	3	2	1	0
• Worked to generate solutions	3	2	1	0
• Worked to document solutions	3	2	1	0

3. Effectiveness in performing assigned role	3	2	1	0
4. Listening and speaking skills	3	2	1	0

Suggestions for team member:

Your Name: ____