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Best Practices Using Clickers Effectively in an Introductory Programming Class

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Abstract

Active and peer learning techniques are proven to be effective teaching methods. One form of active learning that is particularly useful in large lecture-based classroom is the use of clickers. One form of peer learning is incorporating peer discussions into the clicker activity. This paper presents on best practices at designing clicker questions, facilitating clicker responses, and incorporating peer discussions for an introductory programming course. The course used in this study is for underclassmen mechanical engineering undergraduate students. The paper will present both quantitative and qualitative data that demonstrate effectiveness. Lastly, over 18 sample clicker questions are provided for engineering faculty to use directly, or by example.

Keywords: Engineering Education, Active Learning, Peer Learning, Clickers

Introduction and Literature Review

The use of clickers is just one of many active learning techniques that can be easily implemented into a class. The work presented in this paper is part of a course that was designed and ran for the first time in Spring of 2013. It is still running now in the Spring of 2017, which amounts to 7 semesters using the same course design and over 650 students taking the course. The course design and its effectiveness are described in detail in a previous paper (S. Reckinger, 2014), but a brief summary will be provided here. The sample student population is undergraduate Mechanical Engineering students. The primary course goal is for students to learn introductory programming concepts such as using loops and conditional statements, writing functions, and developing algorithms to solve problems using the MATLAB software. The programming is mainly applied to numerical methods, data analysis, and statistical concepts relevant to engineering. The course is taught in an engineering department by a mechanical engineering faculty member, who's research background is in computational fluid dynamics. The curriculum employs many of the active pedagogical approaches including a pseudo flipped classroom (Bergmann & Sams, 2012), Process-Oriented Guided Inquiry Learning (POGIL) method (Farrell, Moog, & Spencer, 1999), clicker questions, and kinesthetic lectures (Sivilotti & Pike, 2007). In addition, traditional techniques are still used such as an abbreviated, concise board lectures and hand-written exams. The course also incorporates peer learning through the use of undergraduate teaching assistants (similar to learning assistants or peer learning group leaders (Otero, Pollock, & Finkelstein, 2010) and partner quizzes (in addition to the peer learning that happens with the clicker methods presented here). A full description of the peer learning techniques can be found in a previous paper (S. Reckinger, 2016). One important note is that the instructor has taught this course at two different universities. The first is a private, Jesuit university in the Northeast (Spring 2013, Spring 2014, Spring 2015). The second is a public, land grant university in the West (Fall 2015, Spring 2016, Fall 2016, Spring 2017). Results will be mixed from different semesters.

The purpose of this paper is to discuss how to implement clickers effectively in an introductory programming course. First, the method of how to facilitate the class through the clicker process will be described. Second, the design of an effective clicker question will be discussed and 18 sample clicker questions are provided as examples. Quantitative results will be presented on student performance on clicker questions. Qualitative results will be provided to show and describe the learning that cannot be measured quantitatively. Students preferences and feedback regarding clicker questions will also be presented, which show students' affect towards the use of clickers in the classroom.

Methods

The facilitation of clicker questions is one of the two most important aspects of using clicker questions effectively. The procedure for using clickers is to provide a question for students to answer and ask them to first individually answer the question. After giving them enough time, the poll is closed and the distribution of answers is analyzed. If approximately 80% of the class or less has the correct answer, a discussion period follows. The instructor explains, "please discuss with your peers at your table (or nearby), come to a consensus on what is the best answer, and click in your answer to this question for a second time." After a few minutes of discussion, the instructor stops the poll again and looks at the results. This process takes substantially longer than just asking the question one time, which is why its effectiveness needs to be very evident to be worthwhile. Previous work has shown that conceptual understanding of material is enhanced when clickers incorporated peer discussion (Smith et al., 2009), which is the motivation for this process. The last point to make is that the clickers presented here are all used as review of material, which was just learned in the previous session or week. Before answering these clicker questions, students have had a full lecture on the material, completed a prelab assignment, and started and/or finished a programming lab. Therefore, this material is new but well-practiced. The clickers are graded for correctness and contribute to a participation grade, which makes up 10% of their final grade. An adequate grade incentive also improves effectiveness.

The design of the clicker questions is the second important piece. The author of this paper has presented this work on many occasions to engineering faculty teaching similar courses. One of the main purposes of this paper is to have sample clicker questions published so that they are available for engineering faculty to use directly or by example. There are 18 sample clicker questions provided in the Appendix of this paper for that reason. These questions are all written by the author of this paper or by Dr. Scott Reckinger, who helped with the Spring 2013 semester of the course. Syntax questions are particularly popular in peer discussions, see Questions 1-3 in the Appendix. The multiple-choice options need to be carefully designed to incorporate misconceptions or common errors. For example, in Question 2, students need to sort out when a dot operator (.) is to be used, what the colon operator does, that parentheses are used for array accessing, and the use of the asterisk for multiplication. Questions, like this, that request which answer would NOT work, are also particularly good at sparking robust discussions. Many of the questions (4, 6-10) are examples of reading and understanding simple codes. These are simple enough that students can figure them out by reading them, but the logic is tricky enough that they induce some intense and productive discussions. Questions 15-18 are examples of doing some computations by hand related the methods that are being programmed in the lab in a much more complex way. These questions are also very popular for discussions.

Lastly, the questions published here are all chosen because they have been used many times and always generate a lot of interesting discussion. However, these are not all the clicker questions used in the class. These published questions are a form of an "open" question. Not in the sense that they have multiple correct answers, they certainly all have a single correct answer. But in the sense that the answer does not close the discussion. These types of questions generate discussion. An example of a "closed" question would be: "What symbol is used for writing a comment in MATLAB? a) ; b)# c)$ d)%". This question can be categorized as closed because if a student is incorrect, the discussion is usually limited to a correction of knowledge on a very specific issue. These questions are useful, especially as warm up questions, but are not good for discussion.

Results

During an end of the semester survey, students were asked, "did you find that the clickers and clicker discussions with your peers helpful to your learning?" Out of all 89 students from both Spring 2014 and 2015 semesters, 60 students (67.42%) said "yes", 0 students said "no", and 21 students (23.60%) said "a little". Towards the end of the Spring 2015 semester, students were assigned seats. This actually greatly enhanced the already successful clicker peer discussions. Several students voiced their support of assigned seating and wished it was that way the entire semester.

Data was collected on the percentage of students answering clicker questions correctly before and after peer discussion. This data has been collected for each semester, when peer discussions were implemented, however, only Spring 2014 data is presented in Table 1 for conciseness. The same trend has been consistent in all semesters of teaching a wide variety of classes using this method. The table shows the percentage of students who answered the clicker question independently, before peer discussion (Independent Q#) and after peer discussion (Peer Q#). The difference between the two is also shown in the adjacent cell. This data is with students' self-selected seats, so they are typically discussing these questions with their peers. In all instances, the peer discussion results in more students arriving at or being convinced of the correct answer. One important note is that clicker questions are typically covering fairly new material, often times the material was introduced for the first time the previous session. Also, questions are only asked twice when there is not an obvious consensus among the class. While the data in Table 1 clearly demonstrates that peer discussions lead to more students clicking in the correct answer, it does not indicate how effective the discussions are at students' understanding of the content. The survey data presented above indicates that students feel that the peer discussions help with their learning.

	Percent of Students who answered correctly	**Difference between Peer Q# and Independent Q#**		**Percent of Students who answered correctly**	**Difference between Peer Q# and Independent Q#**
Independent Q1	29.4%		Independent Q10	70.3%	
Peer Q1	88.2%	58.8%	Peer Q10	97.1%	26.9%
Independent Q2	52.2%		Independent Q11	29.7%	
Peer Q2	78.3%	26.1%	Peer Q11	50.0%	20.3%
Independent Q3	31.6%		Independent Q12	22.9%	
Peer Q3	40.0%	8.4%	Peer Q12	48.6%	25.7%
Independent Q4	60.0%		Independent Q13	38.9%	
Peer Q4	100.0%	40.0%	Peer Q13	60.0%	21.1%
Independent Q5	66.7%		Independent Q14	37.1%	
Peer Q5	80.0%	13.3%	Peer Q14	86.4%	49.2%
Independent Q6	70.6%		Independent Q15	20.6%	
Peer Q6	85.7%	15.1%	Peer Q15	81.0%	60.4%
Independent Q7	39.4%		Independent Q16	39.4%	
Peer Q7	69.4%	30.1%	Peer Q16	79.4%	40.0%
Independent Q8	29.7%		Independent Q17	54.5%	
Peer Q8	43.2%	13.5%	Peer Q17	100.0%	45.5%
Independent Q9	73.3%		**Independent Mean**	**45.1%**	
Peer Q9	92.9%	19.5%	**Peer Mean**	**75.3%**	**30.2%**

Table 1 – Summary of clicker question responses for questions that were asked first as an independent response (Independent Q#) and a second time after students discussed the answer with their peers (Peer Q#). These question numbers to not correspond to Appendix questions.

Peer discussion can be so effective that a group of students who all clicked in incorrectly individually can click in correctly after discussing. The author of this paper has witnessed this in upper division courses, but does not yet have clear evidence of this happening in this introductory class. In a junior thermodynamics course taught by the author, the large majority of students clicked in a wrong answer on a particularly difficult conceptual question. However, after peer discussion, the majority of the class had come to consensus on the correct answer. Showing that it is the discussion that improving learning, not just a simple sharing of the correct answer. In the Appendix, Question 2 has shown similar results, but not as strong (see Table 2). In the Fall of 2016, the majority of the class clicked in the wrong answer after answering individually. After peer discussion, the percent of students clicking in correctly went from 12% to 32%. However, when the same question was asked in Spring 2017, the percentage of students clicking in correctly went down after discussion. This means, some students who originally clicked in correctly were convinced of the wrong answer by their peers. This is the first time the author has witnessed this happening.

	Fall 2016		**Spring 2017**	
	Independent	**After discussion**	**Independent**	**After Discussion**
A	101 (78%)	78 (63%)	68 (72%)	81 (90%)
B	**16 (12%)**	**40 (32%)**	**12 (13%)**	**8 (9%)**
C	12 (9%)	5 (4%)	10 (11%)	1 (1%)
D	0 (0%)	1 (1%)	4 (4%)	0 (0%)

Table 2 - Table of responses to Question 4 in Appendix. The color red highlights the correct answer.

To supplement the quantitative data provided above, a qualitative discussion will follow. Figure 1 shows some images of a class answering a clicker question using the process outlined above. A video would be much more convincing, but not possible for this publication. The first image shows students answering the clicker question independently. The author of this paper is currently investigating how learning styles can affect different teaching and assessment techniques used in engineering education (S. M. Reckinger & Hughes, 2017 (in press)). One interesting learning style dimension relevant to clicker discussions in the active/reflective scale. Active learners learn best when doing, trying, discussing, and moving. Reflective learners learn best when thinking, independent, and in calm/quiet environments. This individual response in particularly useful for reflective learners. It allows them to think through the question on their own before being required to discuss with their neighbors. This response period is generally very quiet and “exam-like”. After responses are collected and analyzed by the instructor, students begin the discussion period. During this time, the room becomes very loud. There is a lot of pointing and air drawing. See the middle photo in Figure 1. Observationally, the discussions are typically enthusiastic and engaging. It is fun to see students discussing their opinions on the question with convection. Active learners find this particularly necessary and they are especially engaged in the discussions. They click in their answers for a second time (receiving credit for both their individual and peer discussion answers). Since students and their surrounding peers are invested in their answers, at this point, there is typically loud groans or hopefully, celebratory high fives and cheers once they find out the correct answer, as see in the third photo of Figure 1.

Figure 1 – Three images of a lecture class where students are answering clicker questions using the process described in this paper.

The instructor has observed the following type of student engagement during these clicker activities. First, there is the disengaged students. These students do no participate in the discussions or do not take the initiative to turn in, turn around, or find another person to chat with. They may benefit from listening to others discuss around them or may not benefit at all from these discussions. Due to the grade incentive, there are not many of these students. Second, there is the flex student. Flex students will engage in discussion if someone else addresses them. They may limit the discussion as much as possible ("yeah, I put that too. Cool, let's click that again.") or may engage if it occurs naturally. Third, there is the reflective discusser. These are students who would normally be rather introverted/quiet/independent, but when given the adequate prep and environment, they become quite active discussers. They typically understand the questions and answers well and will take the opportunity to explain to others who don't, which also benefits their own understanding by forcing them to explain their rationale to someone else. Fourth, there is the active discusser. This person is also very engaged in discussion but takes the discussion period as an opportunity to "talk it out". They need that discussion period to hash out their thoughts, and benefit greatly from some back and forth. Finally, there is the asker. There is also a large group of students who take this opportunity to ask their peers questions: "what did you put?", "what does this mean?", "why doesn't this one work?" These students are great contributors to the discussions. And they pair very well the with the previous two types.

Discussion

The peer discussions after in class clicker questions are incredibly effective and an easy peer learning technique to implement. Students found these helpful and clicker response data also shows their effectiveness. There is evidence that the discussion improves learning and do not simply communicate the correct answer from peer to peer.

Overall, the course is progressing to a successful learning environment for most students. With the careful course design and the addition of peer learning techniques, most data indicates that the course is effective. Pre and post test scores indicate not only that students are developing the desired skills that the course sets out to teach, but also that students are leaving the course knowing more than when they started. Course evaluations show an increase each semester in student's overall evaluations of course learning outcomes achieves, the course overall, and the instructor overall. Students reported a positive affect towards programming once they leave the course, which is a very important result. This could be the single most important result of this course.

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Appendix

1. Given the following array, bear=[3 4 5 8 1 0] defined in MATLAB. How do you access the value 4 inside the array?

    a) bear[2]
    b) bear[4]
    c) bear(2)
    d) bear(4)

2. How to convert degrees=[10 15 70 90] into radians using MATLAB...which one of the codes below would NOT work?

    a) radians=degrees.*pi./180
    b) radians=degrees*(pi/180)
    c) radians=degrees.*(pi/180)
    d) radians=degrees(pi/180)
    e) radians=degrees(:)*pi/180

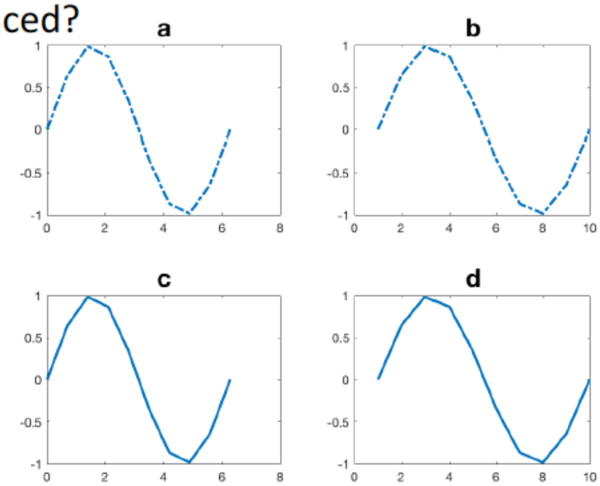
3. If you want to create data for the following function (over the range x=[0:0.1:1]):
$f(x)=x^2+2$
Which of the following MATLAB definitions is correct?

a) $f(x)=x^2+2$
b) f(x)=x^2+2
c) f=x^2+2
d) f=x.^2+2
e) f=x.^2 .+2

4. If you execute the following commands in MATLAB:

```
x=[0:2*pi/9:2*pi];
y=sin(x);
plot(y, '-.')
```

Which plot is produced?



5. For the array, **`p=[2,-1,5,8,-9]`**, what does **`m`** equal after the following command is executed:

`m=p<2`

a) Error, does not run

b) m=[-1, -9]

c) m=[2, 5]

d) m=[0, 1, 0, 0, 1]

6. Follow the code's logic and report what will be displayed:

```
cat=5;
if (cat<=5)
  dog=0;
elseif (cat>5)
  dog=1;
else
  dog=nan;
end
dog
```

a) cat=5

b) cat=0

c) dog=0

d) dog=1

e) dog=nan

7. While Loops – which of the following codes will result in an infinite loop:

a.	b.

count=1;
while count<3
  r(count)=5;
  count=count+1;
end
	count=1;
	while count<3
	  r(count)=5;
	end

8. Follow the code's logic, what will be the value of count after all the code is executed?

```
count=0;
weights=[100 44 75 80 99];
for i=1:5
   if weights(i)<50
      count=count+1;
   end
end
```

a) count=0
b) count=1
c) count=2
d) count=3
e) count=4

9. What value will `iter` have at the end of the following section of code?

```
x=[100 115 131 154 186 203 242 256];
myvalue=203;
iter=1;
while myvalue>x(iter+1)
    iter=iter+1;
end
```

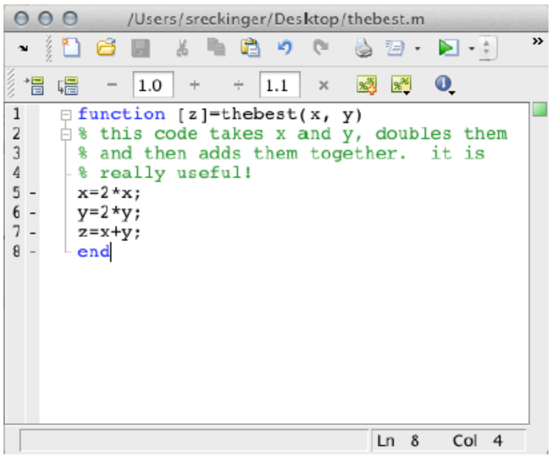
a) Code won't run
b) 1
c) 3
d) 5
e) None of the above

10. How many times will "I LOVE MATLAB" be displayed when the following code is run?

```
for i=1:10
    for j=1:8
        if i>2 & j>2
            disp('I LOVE MATLAB')
        end
    end
end
```

a) 80 b) 10 c) 8 d) 5
e) none of the above

11. Assuming you write the following function in an m-file. How do you run the function with x=1 and y=2 (i.e. which one would run without error)?



a) >>thebest
b) >>thebest(12)
c) >>thebest{1 2}
d) >>[z12]=thebest[1, 2]
e) >>thebest(1,2)

12. You wrote this function:

```
function [result, result2]=myfunc(x,y)
    result=x.*y+4;
    result2=1;
end
```

If I type myfunc(1, 1) in the command window to run this function, what will be printed to the screen?

a) Nothing
b) 5, 1
c) 1
d) 5
e) An error

13. You wrote this function:

```
function [result]=myfunc(x,y)
    result=x.*y+4;
end
```

Which of the following is an <u>invalid</u> way to call your function?

a) `x=1; y=2; result=myfunc(x,y)`
b) `A=1; B=2; AtimesBplus4=myfunc(A,B)`
c) `myfunc(1,2)`
d) `answer=myfunc`
e) `irrationals=myfunc(pi,sqrt(2))`

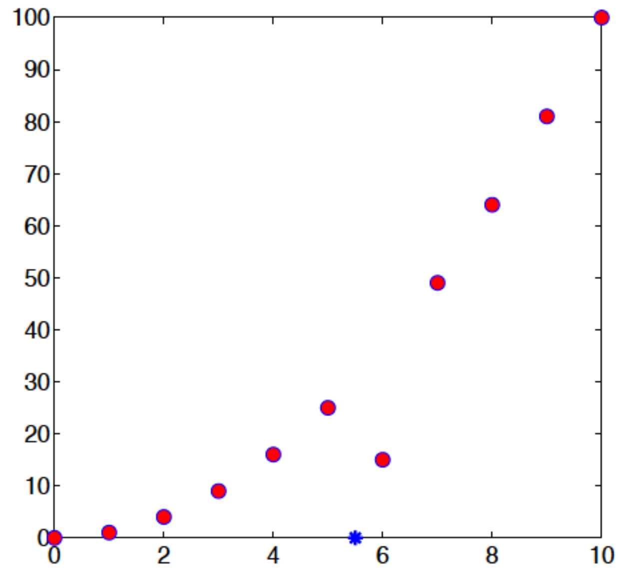
14. What value will `iter` have at the end of the following section of code?

```
a=[-2 0 3 5 6 6 7 8 9 10];
iter=0;
for i=1:length(a)
    if a(i)>5
        iter=iter+1;
    elseif a(i)<5
        iter=iter-1;
    end
end
```

a) 0 b) 3 c) 5 d) 6 e) 10

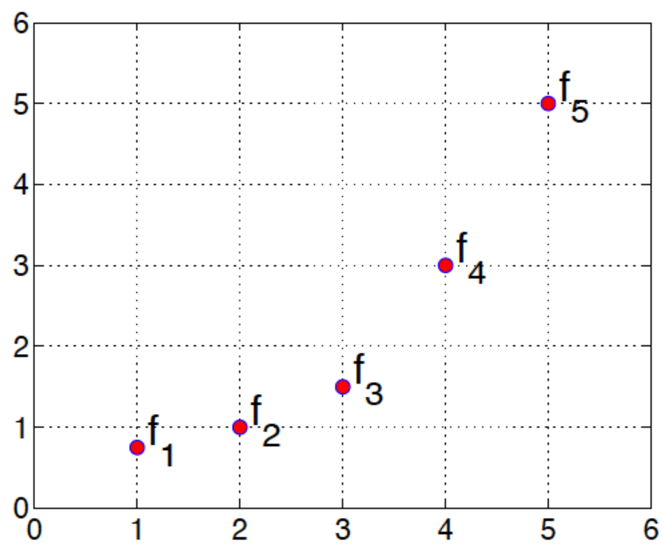
15. What is the linearly interpolated y* value for x*=5.5?

a) 10
b) 20
c) 30
d) 40
e) 50



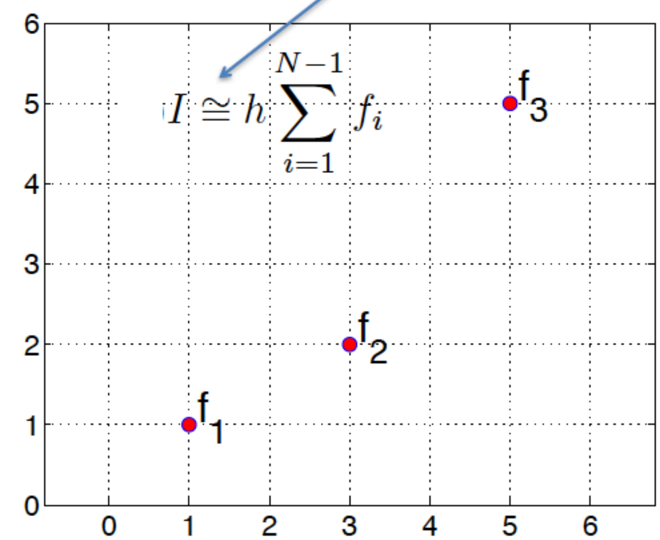
16. What is the numerical derivative f_3' using central finite differentiation?

a) -1
b) 0
c) 0.5
d) 1
e) 1.5



17. What is the numerical integral, from x=1 to x=5, using the rectangular rule?

a) 20
b) 3
c) 15
d) 5
e) 6



18. What is the order least to greatest?

I_{exact} = exact integral of analytical function
I_{trap} = approximate integral using trapezoidal rule
I_{rect} = approximate integral using rectangle rule (left)

a) $I_{exact} < I_{rect} < I_{trap}$
b) $I_{trap} < I_{exact} < I_{rect}$
c) $I_{rect} < I_{exact} < I_{trap}$
d) $I_{trap} < I_{rect} < I_{exact}$
e) $I_{rect} < I_{trap} < I_{exact}$