Two-Way Structures: Enhancing Lecture-Based Structures
Courses with Interactive Personal Response Devices

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Introduction

When we hear the term “two-way structure” in an architectural context, we typically understand this to mean a constructive system designed to distribute load (normally gravity loads on a floor slab) simultaneously in orthogonal directions to the supporting framework, in contrast to one-way structures that transfer them in a linear manner. As a pedagogic concept, in an analogous manner the term is used here to describe a mechanism to facilatate to the interchange and dialog between teacher and student in an otherwise conventional lecture format class.

As the number of students in class grows beyond a certain size, it becomes increasingly challenging to make connections with students at a more personal level. Who that has taught in a lecture class has not at one time or another been confounded by the silence of passive students too timid to speak up even when directly questioned? Studies have demonstrated that, for many students, the traditional classroom lecture is an ineffective means to learning and engagement with subject matter. This is not only a concern in architecture, but other allied disciplines such as civil engineering also face similar, if not identical challenges (see for example Bernold 67).

Active learning techniques have been shown to be an effective approach to breaking down the barrier of distance and passivity in the classroom. The essential notion is to engage students in the learning process and thereby increase understanding and retention while adding participation and interest.[1] Active learning is the third of the seven principles outlined in the seminal *Seven Principles for Good Practice in Undergraduate Education* (Chickering & Gamson).

As an active learning strategy, one of the most effective means of teaching structural concepts to students of architecture is arguably through a studio-type course. Considerable one-on-one dialog can take place in such a setting and basic structural concepts can be applied to hypothetical design projects in a more holistic manner with a great deal of instructional feedback provided. The reality for most schools, however (and particularly at the larger state-funded institutions), is that the relative luxury of teaching structures and related classes in such a resource intensive manner is not financially possible, however desirable it might be pedagogically.

In most cases, then, the lecture format is likely to be the predominate mode of in-

Figure 1 Typical Personal Response Devices in Use (Photo Courtesy Turning Technologies, LLC)

structional delivery. Yet despite their proven successes, the possible range of active learning techniques is more limited in larger lecture class settings, and even more so in rooms with fixed seating. So with class sizes of 75, 100 or more being not uncommon, we remain confronted with the dilemma of how to connect with and engage a larger body of students. However, at a growing number of institutions around the world a quiet revolution has been taking place over the past decade in the way large format lectures are being conducted, one that at least in part addresses this challenge through modern technology.

Known variously as "personal response devices," "'audience (or classroom) response systems"'—or simply as *clickers* or *keypads* in the vernacular, as the systems will be referred to herein—these small handheld devices offer a technological means to stimulate active learning environments. When properly employed, clickers can generate more enthusiastic student participation by creating an immediately responsive two-way learning experience, one not easily attained through other active learning approaches in larger class settings.[2]

Clicker implementation essentially consists of a receiver connected to a computer at the professor's end and a remote keypad used by students to provide responses to questions and situations shown in a Microsoft PowerPoint-type of presentation. Class response results can be instantly tallied giving students and professor alike an immediate feedback to the level of understanding on the question. With such systems it is possible, for example, to know whether students are "getting it" during the lecture itself, not merely later on during an exam, and adjust lecture content dynamically as needed. Carefully crafted questions can generate polarized responses that can then be turned into peer discussion/learning exercises. Depending on the software used, additional possibilities such as group competition and in-class quizzes are also possibilities.

Originating in the sciences first in the mid 1990s, the use of clickers is becoming increasingly widespread in a number of disciplines. At my university, as a part of a pilot study being made campus wide,[3] I spearheaded the use of clickers in the structures curriculum for architecture students for the first time in the spring semester, 2006. The remainder of this paper will illustrate how they have been used in the introductory structures class, some of the results of this usage, what has been learned so far, and how they are envisioned to be employed in future course offerings. Although a number of such response systems are available (each with their own particular strengths and weaknesses), experiences cited herein are based on the standard system being adopted at the University of Maryland, known as "TurningPoint," marketed by Turning Technologies, LLC.

Enabling Technology

On the popular TV game show "Who Wants to be a Millionaire?" when confronted with uncertainty in their answer to a question, one option contestants are given is to "poll the audience." In so doing, audience members provide what they believe to be the correct answer using a keypad at their seat. The results are immediately tallied by computer and provided in a graph as an aid in the contestant's decision-making. This is essentially how clickers operate in a classroom setting as well. But not being game show hosts, what exactly are the types of things that we can do with clickers in the lecture hall?

It should first off be realized that the clickers are a tool that needs to be properly applied, and that in and of itself cannot make bad teaching good. But, well employed, clickers can be used to facilitate a review of key concepts after a lecture presentation for example, or to conduct class assessments such as obtaining demographic or other background information, to get baseline understanding of a topic, or take polls on sensitive topics that many students might be

disinclined from responding to in a non-anonymous manner. If the software is set up to record the student answers explicitly versus anonymously, then scored 'mini-quizzes' and tests are possible, as well as keeping track of attendance simply by checking if the student answered the questions given that day. In addition, depending on the software used, it is possible to do more advanced functions such as conducting in-class competitions. But perhaps most importantly, they can be used to facilitate peer learning experiences and student-to-student engagement through questions designed to provoke discussion. In whatever manner they are used, the responses are immediately displayed for all to see, and therein lies the power of the instrument.

Data generated from the clicker polling is also not static to the one slide being shown, but all questions and responses in a given presentation are stored in a computer document that the software can then use to create reports in Microsoft Word or Excel. I have personally found the MS Excel reports to be most useful. A log is kept of each day's questions and answers from each student in a cumulative spreadsheet with a separate tab for each class period. By inspecting these reports, it is possible to obtain a clear performance picture for each individual student through the course of the semester. Attendance information is logged into another spreadsheet used for grading.

Framing Questions to Elicit Dialog

Figure 2 illustrates a typical PowerPoint slide that includes both a question as well as student responses after being tallied by the computer. Initially any given slide has just the question with possible answers, and remains with no tallying until either an automatic countdown timer (if so set on the slide) reaches zero, or the instructor terminates the response period.

This question was asked during the next class day following an in-class exercise designed to help develop a physical feel for the relationship of rope tension to inclination. In the exercise, pairs of student volunteers were asked to pull on each end of a rope with a 25-pound weight suspended in the middle in order to lift it from the ground. This was done several times with progressively flatter angles to the horizontal, where clearly an ever-increasing force was needed to lift the weight from the floor. At very low angles, even the strongest men in class were barely able to lift the weight!

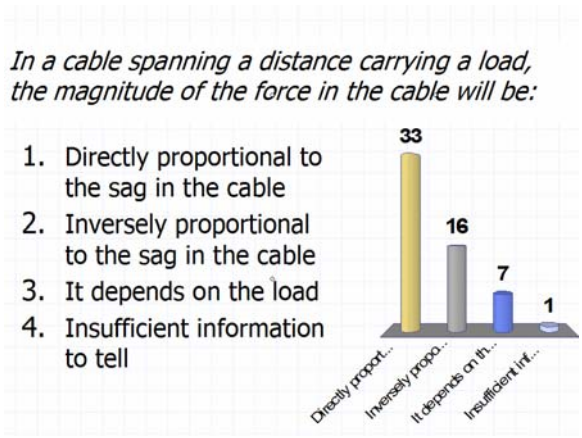

Figure 2. Typical PowerPoint slide with question and tallied student responses.

As can be seen in this case, a common misconception that force in a cable is directly proportional to its sag (versus the correct answer of inversely proportional) was held by 33 of the 57 students responding (these numbers can also be set to display in percentage). So in this instance more than half of the class either did not correctly understand the concept or otherwise misinterpreted the answer, despite the in-class rope demonstration the previous day. The concept was then reiterated and discussed once more to ensure that a broader understanding was achieved, and that students would become more aware of subtleties in their thought processes.

One of the best learning events that can occur with clickers, though, is when a question is posed such that it will elicit polarized responses…that is to say when roughly half of the class chooses one answer, and roughly half select another. Take for example the

"What are the correct senses for the unknown vectors in the system below?"

1) A-Comp., B-Tension
2) A-Tension, B-Comp.
3) A-Tension, B-Tension
4) A-Comp., B-Comp.
5) Impossible to tell

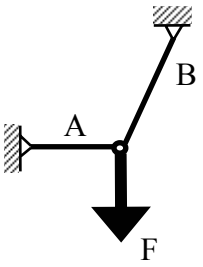

Figure 3. Clicker question on vector equilibrium

qualitative question posed in Figure 3 with regard to vector equilibrium. Here students were asked to mentally reason out the correct sense (tension or compression) of the two members supporting a force "F". The initial responses to the question are summarized in Table 1:

	(Percent)	(Count)
A-Comp., B-Tension	45.3%	24
A-Tension, B-Comp.	3.8%	2
A-Tension, B-Tension	49.1%	26
A-Comp., B-Comp.	0.0%	0
Impossible to tell	1.9%	1
	100%	53

Table 1. Initial responses to question posed in Figure 3

It is evident that roughly equal numbers of students were divided between member "A" being either a tension member or a compression member. But now rather than simply *explaining* the correct answer to the class, this polarization can then become a teachable moment for an active learning exercise of peer engagement, where students can be asked to speak with one another. At this point typically I will say, "Okay, whatever answer you chose, take two minutes to talk with your neighbor and convince them of why you think you are correct."

After the two minutes are up, the same question is re-polled. In this case the results are summarized in Table 2. As can be seen, there was a substantial shift of the majority of the class to the correct answer of both members "A" and "B" being in tension. At this point with the class engaged and more alert from an active participation exercise, a further discussion can ensue explaining how one can mentally (or with a quick sketch) break down the vectors into their components and do a quick non-numeric equilibrium analysis.

	(Percent)	(Count)
A-Comp., B-Tension	17.0%	9
A-Tension, B-Comp.	0.0%	0
A-Tension, B-Tension	83.0%	44
A-Comp., B-Comp.	0.0%	0
Impossible to tell	0.0%	0
	100%	53

Table 2. Responses to question posed in Figure 3 after peer discussion

In another example, a true-false question about moment was posed following the previous class where the concept of moment was introduced: "The sense of a moment is either positive or negative" (Table 3).

	(Percent)	(Count)
True	67.3%	37
False	32.7%	18
	100.0%	55

Table 3. Responses to question about moment sense

Although not equally polarized, enough students did not grasp the notion that moment is described as clockwise/counterclockwise versus positive and negative that it was clear further elaboration was needed. A similar period of peer discussion then ensued, followed immediately by another re-polling of the question. Data in Table 4 illustrates a substantial shift in understanding after the peer discussion period.

	(Percent)	(Count)
True	34.5%	19
False	65.5%	36
	100.0%	55

Table 4. Re-polling responses to question about moment sense

In addition to using clickers to stimulate discussion, following suggestions in the literature, periodic and typically unannounced "clicker quizzes" were given throughout the semester (Duncan 39). These questions were essentially similar to others, however they were given a value of two points for a correct answer and one point for an incorrect answer. Counting overall for 5% of their final grade, this was done to provide an incentive for students to attend class, and to act as token rewards. Generally the questions were kept simple and any calculations were of a very basic nature (For example as in Figure 4). The point values are low enough so that even if a student incorrectly answered every question for the entire semester (unlikely) the worst it could hurt the grade is by 2.5% of the final total in a 600 point class, or 15 points. Additionally, students were informed that the lowest four clicker grades would be dropped so as to alleviate concern for missing a class or perhaps forgetting or losing their keypad.

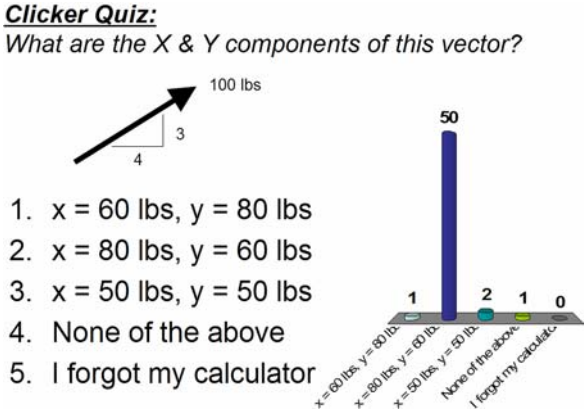

Figure 4. Typical "Clicker Quiz"

Back 'atcha

In the spirit of the two-way structures class, the learning experience is not just on the part of the student, but also for the instructor as well. One of the things I have learned from the student responses, for example, is that sometimes wording I took for granted was at times the source of confusion. For instance, in one clicker quiz, I asked students a question I pose every year in the entry-level structures class regarding the influence of span direction of decking and the resulting load shape on the supporting member. This question read "Decking framing perpendicular to a member produces a load on this member that is:" (the possible answers being 'uniformly distributed,' 'concentrated,' uniformly varying,' and 'insufficient information to tell.'

In the past I had implicitly taken the use of the word "framing" as a verb when used in this context. But I learned here that some students were confused by the question ("we don't understand what you're asking") because they had taken "framing" as a noun. Even though I had used this very question on quizzes and exams many times before and most students did in fact answer it correctly, I had never previously received feedback that the wording itself was a source of confusion for a certain number of students.

In another situation, when discussing buckling behavior a recurrent struggle with some students is in developing a correct understanding for the influence of cross sectional shape. Which axis is the 'major' and which is 'minor' seems to typically be problematic for about one third of any given class. Though I go to great lengths to make very clear the distinction of "major axis" versus "minor axis," it was only after posing a clicker question that read "Identify the strong axis of a column with the cross-sectional shape below" did I come to learn that some students were interpreting "strong axis" to mean the ***direction*** in which the column is most resistant to buckling. Since bucking occurs *about* an axis, if we say that the larger moment of inertia is about the x-axis, it will be most resistant to buckling movement in the *direction* of the y-axis…and thus some students interpret this to mean that the strong axis is the y-axis because it is not inclined to move in that direction. This is a very subtle distinction, one that I had heretofore not picked up on

but which I will be certain to be clear about with future classes.

Problems in Paradise

Despite the promise, at present all is not golden and there are hidden 'costs' and challenges that go along with the technology. To paraphrase a saying, it is seldom that a solution to one problem does not itself breed new problems. As with any new technology there are bound to be unforeseen difficulties with its early implementation, both in terms of the learning curve for the user as well as in maturity of the software itself. It is therefore important when adopting a new device such as clickers that one be careful to not overdo things or hold initial expectations too high.

With regard to the learning curve, despite the glitzy show of the corporate presentations touting its ease of use, I found that even with a fairly strong background of computer usage it took a substantial time investment in the early part of the semester in learning to use this tool. Of course in being a part of the pilot program on campus I'm at the "bleeding edge," as it were. A well-developed training program for users has yet to emerge, which in time will alleviate the struggles of learning its use on one's own.

Operationally (at least with the version of TurningPoint we used) I found that PowerPoint itself ran more sluggishly and took noticeably longer to start up. In addition, undocumented characteristics, poorly documented features and specific operational quirks were frustrating. At times I could sense irritation in some students with occasional system problems and things not always going according to plan in class. I discovered, for example, that unless one is using a dual computer/projector setup, one cannot easily embed many photo images with clicker questions in the same presentation. Doing so creates difficulties in terms of generating excessively large response data file sizes and file save times that strain computing resources. For now, my workaround is to either not include or otherwise greatly limit the use of images in presentations with clicker questions. This operational encumbrance significantly limits the flexibility in usage of the system at present.

Nevertheless, these issues should be taken as growing pains attributable to early adoption, and some are likely unique to this particular software package. It does, however, underscore that one should expect the unexpected. Feedback has been delivered to the software vendor that hopefully will result in corrections to these and other limitations. Furthermore, as with anything else, effective and efficient use also comes with user experience. The literature indicates that with continued usage, the favorable response from students about the use of clickers increases.

Finally there can also be the cost factor assumed by the student. Although some publishers are bundling clickers with textbooks, this only works with compatible software systems. Some schools may also purchase clickers that stay with the room and students only use them in that class, but this limits the student-specific information that can be gathered. At the University of Maryland, students are required to purchase the keypads for $48. Although to a student this cost is not trivial, they may sell them back to the bookstore at half cost, or sell them to an upcoming student the next year, so the expense is mitigated and can be thought of more akin to a 'rental' fee. Since the system is being adopted here campus-wide, it is anticipated that incoming freshman students will purchase the keypads and retain them throughout their college career and use them in multiple classes.

Some Initial Outcomes and Surprising Findings

In the final class for the semester, an anonymous survey using clickers was taken to assess the impact and effectiveness of

their use. Questions related to clicker usage in specific are shown at the end of this document. Other questions related to specific course activities were also asked but have been omitted as being out of context in this presentation. Some questions of a similar nature were asked more than once where there was something I was very specifically interested in knowing, such as how much students felt clickers helped their learning experience.

The results of this initial implementation, while very encouraging, are also not overwhelmingly positive and indicate that there is ample room for improvement in the effectiveness of this new tool. But considering that this is the first time the system has been employed and that the learning curve was at times steep, this is not surprising. And in point of fact approximately one half of the students polled either 'agreed' or 'strongly agreed' that clickers made the class material more engaging.

There was a fairly even polarization of opinion whether clicker questions should have point values in the form of "clicker quizzes," with 20 students either 'agreeing' or 'strongly agreeing,' and 19 either 'disagreeing' or 'strongly disagreeing,' and the remainder being 'neutral.' For the most part, students were no more inclined to come to class when they otherwise would not have because of the clickers.

A few results were quite astonishing. For one, I learned that over two-thirds of the class either seldom or never read or consulted the class textbook (*Structures,* by Daniel Schodek). Even more surprising was that 6% seldom and 92% never used the CD-ROM that comes with the text which contains sample problems and excellent step-by-step presentations—this despite showing the CD in class on a number of occasions. I continue to ponder the meaning of this and how to address it, with one possibility being the use of clicker quizzes immediately following assigned reading.

Looking to the Future

Having now worked with clickers for one semester, many of the system 'bugs' are now worked out. The learning curve has leveled and I have become comfortable with most all features of their use. The initial results are encouraging enough to indicate that with continued practice, clickers will have a useful place in the teaching of this and other similar lecture classes. In specific, I plan to implement the following changes in the fall semester:

- Using clickers in connection with in-class demonstrations (e.g., "what do you think will be the behavior or this element?" etc.)
- Clicker quizzes right after lecture presentations to reinforce the key ideas. Students who frequently don't take notes may find more incentive to do so.
- Outcome assessments immediately after a lab session or project
- More repetition of principle ideas and questions on basic concepts

Conclusion

That clickers are a useful means of engaging students in the classroom has been demonstrated repeatedly through careful studies in a variety of disciplines. The evidence strongly supports that this technology facilitates active learning environments in large lecture settings, increases student interest and enthusiasm, and helps provide feedback to their level of understanding. In the context of teaching structures to architectural students, this is potentially an important technology to combat the "snooze factor" commonly encountered. Structures class need not be so dryly abstract that it drives out the desire to learn it from our students. But technical competence at some level is expected and clickers represent one more tool in our belt to help develop the best critical thinking skills in the future generations of young professionals.

Appendix: Representative Exit Survey Question Results

The semester exit survey was given with the clickers in an anonymous mode, controllable by the software, to help ensure sincerity of response. Representative questions from this survey and the response rates are shown below. There were several students absent that day, as well as another few who forgot their clickers or had problems, so the sample is less than the full class size of 58.

The numbers at the far right of each table represent the number of responses to each question choice, and the corresponding percentage of those who responded. Note that not all students responded to all questions. This at times is due to functional problems with the keypad device (not pushing the button properly) and, I believe, a certain amount of apathy among those students who feel the clickers are not a useful tool. Perhaps another question could be added to this reading something like "If you did not respond to each question, please indicate your reason."

The use of clickers has made this course material more engaging

Strongly Agree	8.3%	4
Agree	41.7%	20
Neutral	29.2%	14
Disagree	12.5%	6
Strongly Disagree	8.3%	4
	100.0%	48

For me, earning "clicker points" motivates me to come to class

Strongly Agree	4.0%	2
Agree	28.0%	14
Neutral	26.0%	13
Disagree	18.0%	9
Strongly Disagree	24.0%	12
	100.0%	50

Clicker questions helped me to know how well I was learning the material

Strongly Agree	4.1%	2
Agree	36.7%	18
Neutral	22.4%	11
Disagree	24.5%	12
Strongly Disagree	12.2%	6
	100.0%	49

I chose my answer to each clicker question carefully

Strongly Agree	25.0%	12
Agree	37.5%	18
Neutral	22.9%	11
Disagree	12.5%	6
Strongly Disagree	2.1%	1
	100.0%	48

By using clickers in this class, I got feedback on my understanding of class material

Strongly Agree	8.0%	4
Agree	42.0%	21
Neutral	26.0%	13
Disagree	16.0%	8
Strongly Disagree	8.0%	4
	100.0%	50

Clicker questions should periodically have point values ("clicker quizzes")

Strongly Agree	8.3%	4
Agree	33.3%	16
Neutral	18.8%	9
Disagree	20.8%	10
Strongly Disagree	18.8%	9
	100.0%	48

I attended class when I otherwise would not have because of the clickers

Strongly Agree	8.5%	4
Agree	12.8%	6
Neutral	17.0%	8
Disagree	25.5%	12
Strongly Disagree	36.2%	17
	100.0%	47

I used the course web site:

Frequently	12.5%	6
Fairly often	31.3%	15
On occasion	43.8%	21
Seldom	10.4%	5
Never	2.1%	1
	100.0%	48

I read and consulted my textbook:

Frequently	2.1%	1
Fairly often	4.2%	2
On occasion	25.0%	12
Seldom	41.7%	20
Never	27.1%	13
	100.0%	48

I consulted the book-supplied CD:

Frequently	2.0%	1
Fairly often	0.0%	0
On occasion	0.0%	0
Seldom	6.1%	3
Never	91.8%	45
	100.0%	49

When planning an architectural space in my studio projects, I see structural principles as influential in my decision-making:

Strongly Agree	14.3%	7
Agree	40.8%	20
Neutral	22.4%	11
Disagree	18.4%	9
Strongly Disagree	4.1%	2
	100.0%	49

As supplementary learning experiences to the more calculation-based material, the hands-on projects (in-class and assigned) were:

Very helpful	12.0%	6
Somewhat helpful	56.0%	28
Neutral	20.0%	10
Not very helpful	10.0%	5
Useless	2.0%	1
	100.0%	50

When looking at the natural environment, I now see structural forces and patterns that were always right in front of me that I never took note of before:

Strongly Agree	2.4%	1
Agree	65.9%	27
Neutral	22.5%	9
Disagree	7.3%	3
Strongly Disagree	2.4%	1
	100.0%	25

How many hours per week did you typically spend on this class outside of lecture?

More than 12	2.2%	1
10-12	6.5%	3
8-10	6.5%	3
6-8	39.1%	18
Less than 6	45.7%	21
	100.0%	46

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Notes:

[1] The literature available on Active Learning has grown to staggering proportions in recent years, and active learning theory falls outside the scope of this paper. The reader is directed to publications including books such as Silberman's *Active Learning: 101 Strategies* for very practical techniques, and to Internet recourses such as the *Active Learning Site,* which provides links to scores of publications in a wide array of disciplines.

[2] For an in-depth scholarly study of the research available on classroom response devices, the reader is directed to Banks (2004), which contains more than two dozen papers by authors in a wide array of disciplines.

[3] A study made by the University of Maryland Robert H. Smith School of Business (Shmueli and Malaga) determined that the TuningPoint system by Turning Technologies offered the greatest benefit over competing vendors, largely due to the integration with Microsoft PowerPoint and a more fully-developed software at the time of the study. Following a later separately conducted campus-wide study that took into consideration a favorable pricing structure offered by Turning Technologies, TurningPoint has been established as the new University Standard. An ongoing pilot program jointly run by the Center for Teaching Excellence and the Office of Information Technology is now underway in departments throughout campus, including my structures class in the School of Architecture, Planning and Preservation.