DESIGNING A WEB-BASED APPLICATION TO SUPPORT PEER INSTRUCTION FOR VERY LARGE GROUPS

Research-in-Progress

Dennis Kundisch, Philipp Herrmann, Michael Whittaker, Marc Beutner, Gregor Fels, Johannes Magenheim, Wolfgang Reinhardt, Michael Sievers, Andrea Zoyke
University of Paderborn
Warburger Str. 100, D-33098 Paderborn
{dennis.kundisch|philipp.herrmann|michael.whittaker|marc.beutner|fels|
jsm|wolle|michael.sievers|andrea.zoyke}@uni-paderborn.de

Abstract

In this research, we introduce a web-based open source solution that enables the transfer of the widely established Peer Instruction approach to lectures with in excess of 350 participants. The proposed solution avoids several existing technical flaws that currently hinder the further adoption of Peer Instruction. We test our solution in a series of lectures with over 500 participants. Within these tests, we evaluate our prototype using the Technology Acceptance Model, the System Usability Scale, as well as qualitative interviews. Both the evaluation results and the feedback from course participants indicate that our new solution is a useful artifact for implementing Peer Instruction in lectures with very large groups.

Keywords: Information System Design, Peer Instruction, Open Teaching Concept, Classroom Response System, Student Activation, Interaction

Introduction

"Physicists and physics educators have realized that many students learn very little physics from traditional lectures." (Crouch et al. 2001)

Researchers have widely documented undergraduate and graduate students' understanding of central concepts in different areas. They have concluded that traditional lecture-style courses contribute only little to the students' understanding of these central concepts (e.g., Beichner et al. 2000; Crouch et al. 2007). At the same time, it is well established in the literature that students develop complex reasoning skills most efficiently when they actively participate in the subject matter (e.g., Crouch et al. 2001; DeCorte 1996; Hake 1998). Active participation vitalizes and supports the students' learning process much better than the traditional lecture style. One way to foster such participation in the lecture is to integrate cooperative activities among students using *Classroom Response Systems* (CRS) (also referred to as, e.g., *Audience Response Systems, Classroom Feedback Systems, Student Response Systems*). A CRS is any system used in a face-to-face setting to poll students and gather immediate feedback in response to questions posed by instructors. CRS have been tested and used in higher education classrooms since the 1960's (Judson and Sawada 2002). In different meta-analyses the benefits of CRS have been documented (Fies and Marshall 2006; Roschelle et al. 2004). Over the past decades, technologists have developed and refined electronic CRS that allow students to key in responses using so-called "clickers". The main advantages of electronic CRS over non-technical methods for gathering feedback are, amongst others, the possible anonymity of responses (Draper and Brown 2004) and the ability to immediately project response graphs for the class to see. In addition, Stowell and Nelson (2007) find that classroom participation is higher when electronic CRS are used compared to conventional CRS. Thus, instructors are mostly relying on electronic CRS as instructional tools in the classroom today (e.g., Cleary 2008).

One specific usage for CRS is that it can assist *Peer Instruction* (PI) (Mazur 1997a), a cooperative teaching and learning approach that is well-suited for involving students even in large auditoriums. Technically similar to the ask-the-audience lifeline in *"Who Wants to Be a Millionaire?"* students get involved in the lecture by using clickers to answer multiple-choice questions posed by the instructor. The questions are designed to engage students and to expose potential difficulties with the material. If the questions are not answered correctly, course participants are encouraged to discuss their answers with their peers or the presentation is repeated in a modified way. The benefits of PI have been established in many empirical studies using varying methods across different disciplines (see, e.g., Crouch and Mazur 2001; Crouch et al. 2007; Fies and Marshall 2006). However, until today, PI has been rarely used in very large groups, i.e., groups of (well) above 350 students. One major reason for the comparably slow dissemination of PI is the cost of the infrastructure for electronic CRS that is mostly driven by physical clickers and/or software licensing fees. Moreover, in interviews conducted by the authors, instructors have mentioned the complexity of software solutions and the need for installation as further important technological barriers to the use of PI.

Given the widespread proliferation of smartphones, laptops, netbooks, and other web-enabled end-user devices among students, having recourse to web technology would appear to be a promising way to avoid the cumbersome and costly infrastructure investments normally required for PI. A review of existing PI solutions indicates that the CRS market has recently developed in this direction, but important hurdles remain if a more widespread adoption of PI is to be achieved. In order to help create a technically and didactically favorable environment for the transfer of PI to large audiences, we initiated the PINGO (Peer Instruction for very large Groups) project. The goal of this project is to develop a scalable, web-based, cost-efficient and user-friendly PI application for students and instructors. Hence, we introduce and evaluate a prototype of our web-based solution (referred to as the *PINGO system*). We report early results from the evaluation of the PINGO system using the Technology Acceptance Model (TAM), the System Usability Scale (SUS) as well as qualitative interviews. To reach the project's goal and to contribute to the knowledge base, we follow the Design Science research paradigm (Hevner et al. 2004).

Peer Instruction

The development of PI is mainly attributed to the Harvard-based physicist Eric Mazur, who developed the method more than 20 years ago (Mazur 1997a). PI has since been established in many universities and colleges as a common teaching and learning approach (Lasry et al. 2008). In the beginning PI was primarily implemented in physical sciences classes, but nowadays is also used in many other disciplines (see, e.g., Caldwell 2007; Lantz 2010). The dissemination of PI was accompanied by an intensive and systematic discussion in the literature about the benefits of the method. For instance, Crouch and Mazur (2001) show that PI, used in a particular disciplinary context, produces large and statistically significant improvements in standardized test results. Likewise, other researchers report positive anecdotal or empirical evidence for the benefits of PI (see, e.g., Cortright et al. 2005; Fagen et al. 2002; Fagen 2003; Feeley 2012, Kay and LeSage 2009b; Lantz 2010; MacArthur and Jones 2008; Miller et al. 2006; Moss and Crowley 2011; Pilzer 2001, Porter et al. 2011a, Schmidt 2011, Zingaro 2010). One constituting characteristic of PI is that student-student interactions in small group settings alternate with whole-class evaluations (Lasry 2008). Crouch and Mazur (2001) describe PI as follows: *"The goal of PI is to transform the lecture environment so that it actively engages students and focuses their attention on underlying concepts. Instead of presenting the level of detail covered in the textbook or lecture notes, lectures consist of a number of short presentations on key points, each followed by a ConcepTest – short conceptual questions, typically posed in a multiple-choice format, on the subject being discussed."* The instructor proceeds by tailoring his lecture to the outcome of the ConcepTest: In case of a high proportion of correct answers, she continues with the next topic. In case of a significant proportion of wrong answers, either the presentation will be reiterated in a modified way, or students get the opportunity to discuss their answers with their peers – and that is where the name of the method originates. Either way, the course participants re-do the same ConcepTest after the repetition or the peer discussion. Typically, the number of correct answers increases, which can be attributed to gains in understanding (Smith et al. 2009). Once again, the instructor decides how to proceed based on the distribution of the answers.[1]

Using PI in a lecture helps to overcome the often rather passive role of students and, thus, enables them to become active designers of their own lecture. Through this cooperative teaching and learning method and, in particular, via peer discussions, students are able to better reflect on new course content, and to interpret and link this content with existing knowledge (e.g., Brooks and Koretsky 2011, Cortright et al. 2005). Furthermore, PI stimulates the problem-solving capabilities of course participants (e.g., Cortright et al. 2005; Giuliodori et al. 2006) and may foster teamwork and communication skills (Porter et al. 2011b). Unlike in traditional one-way lectures, the focus in courses using PI is not on the mere transfer of content. Instead, students are urged to prepare for the lecture beforehand to be able to answer the ConcepTests (Crouch et al. 2007; Mazur 1997b). Thus, each lecture becomes a focal point for the clarification of ambiguities and questions, the discussion of concepts that are difficult to understand, and the linking of the content with prior knowledge.

Since the mid-1990s, the implementation of PI in lectures has been supported with appropriate information technology (IT). Typically, the instructor projects ConcepTests using a video projector. The students place their answers via clickers that are the size of a remote control. An electronic CRS – typically consisting of clickers, some kind of receiving device and appropriate software – collects the responses from the registered clickers and immediately displays the results on the projector. Despite this far-reaching IT support, a variety of issues remain for the PI (or other CRS-based pedagogical approaches) not to be implemented more widely. These issues include *technological challenges, teacher-*

---

[1] We note that this is an ideal-typical description of the method implementation. There is some variation in the actual implementation dependent on the instructor (see, e.g., Turpen and Finkenstein 2009, Turpen and Finkelstein 2010, Simon et al. 2010). In addition, we note that researchers of the "Physics Education Research Group" at the University of Massachusetts have also come up with a conceptually similar approach that emphasizes more class-wide discussions (Dufresne et al. 1996). We focus on PI here because a comparison of the two approaches indicated that PI "*was perceived by students to be more beneficial to learning than class-wide discussion*" (Nicol and Boyle 2003). For a general review of the literature on different teaching strategies with CRS usage see Kay and LeSage (2009b).

centered challenges (e.g., responding to student feedback, subject coverage, developing questions), as well as *student-centered challenges* (e.g., new method of learning, confusion in discussions, being monitored) (see, e.g., Boyle and Nicol 2003; Fagen 2003; Heirred 2006; Kay and LeSage 2009a; Rao and DiCarolo 2000; Stuart et al. 2004; see Kay and LeSage 2009a for a useful review of the CRS-literature in this respect). In this paper we concentrate on technological and infrastructure-related challenges while acknowledging that solving technological challenges alone will not be sufficient to realize the full potential of PI and other CRS approaches. Specifically, we have identified the following technological challenges:

1. **Clicker administration effort**: Setting up the system and distributing and collecting the clickers in courses with about 100 students is a time-consuming task (e.g., Grainger et al. 2011, Stuart et al. 2004); at present it is nearly impossible in courses with over 350 students – unless the students are obliged to buy their own clicker at the beginning of their course or studies (Herreid 2006). This is common procedure at some universities, although complaints have been reported (Patry 2009). Naturally, the risk that anonymously distributed, university-owned clickers are forgotten, lost, damaged or even taken away rises disproportionately with increasing group sizes.
2. **Installation**: Typically, an installation of software on the laptop of the instructor is required. Thus, a spontaneous usage of a different laptop is not possible (e.g., Stuart et al. 2004). In addition, the software installation is not possible for all operating systems and the common integration of the application in PowerPoint is not systematically supported in all versions of Microsoft Office.
3. **Configuration**: Dependent on the chosen solution, the preparation of the very detailed configurable software for the usage in a lecture may cause high setup costs for instructors (e.g., Butchart et al. 2009). Moreover, the order of the questions may not be adapted dynamically and effortlessly during the lecture.
4. **Exclusive use**: The use of clickers is exclusive, i.e., when the clickers are used in one course, they cannot be used in another course by a different instructor at the same time.
5. **Costs**: The clickers and the receiving device are expensive (see, e.g., Herreid 2006; Salemi 2009).

We address these issues within the PINGO project. To do so, the first step was to compile a list of requirements. Subsequently, we matched the requirements with available solutions in the market.

Requirements and available solutions

To compile a list of technical requirements and in light of the challenges listed above, we performed various interviews with instructors that have used PI in conjunction with physical clickers for many years in their lectures at different universities. Further, we talked to a number of instructors that are currently not using PI, but would be interested to do so. The requirements are summarized in Table 1. *Prevention of unauthorized usage* and *real-time capabilities* were not explicitly added to the list, as these two requirements naturally have to be satisfied by all imaginable solutions.

In the next step of the design process, we undertook a market research to identify already available solutions and compared them with the requirements (see Table 1).[2] Overall, we identified 36 providers of CRS solutions that may be used for PI (name of the product that matches best with the requirements in brackets): Andy Schwen (WiFli Student Response System), Audio General Inc. (ConVa), BeyondQuestion (BeyondQuestion), Big nerd Ranch (eClicker), Califone (Got It!), eInstruction (vClicker), ELMO (CRV), Fleetwood Group (Reply), Go Education (GoSoapBox), H-ITT (Softclick), iClicker (webClicker), IML (Click & IML Viewpoint Express), intellididact (intellivote), iRespond (iRespond AnyPlace), isee (ISEE Active), IVS (Interactive Voting System), Learning Catalytics (Learning Catalytics), LearnStar (Starlite), Meridia (MyVote), Option Technologies Interactive (OptionFinder), Parallel Divergence Software (Student Response Network), Poll Everywhere (Instant Audience Feedback), Polar Dynamics (QuestionPress), PowerVote (PowerVote), Promethean (ActivEngage), QOMO HiteVision (QClick), Qwizdom (Qwizdom), Renaissance Learning (2know!), Sergiy Krutykov (Power Blue Classroom Quiz),

---

[2] Last updated: 15th August 2012, based on publicly available data. We assume no liability for the accuracy of the data. Due to space restrictions we do not report a comprehensive review here. A current list of CRS providers with further information is available on request from the authors. A review of leading brands of radio-frequency clicker systems can also be found, e.g., in (Barber and Njus 2007).

Smart (SMART Response VE), Sunsky Electronic (ARS/CRS/PVS), Texas Instruments (TI-Navigator), Textthemob (textthemob), Turning Technologies (ResponseWare), University of North Carolina (Numina), and Wake Forest University (ClassInHand). We take the substantial number of providers as an indication for the relevance of CRS in lecture halls.

Table 1. Requirements		
Requirement	**Corresponds to challenge**	**Description**
1) Usage	Configuration, Installation	The artifact should be intuitively usable for both instructors and students, without the need to refer to a tutorial. The artifact should support dynamic and effortless adaptations during the lecture, for instance, in terms of question format asked (e.g., single-choice or multiple-choice).
2) Scale	Exclusive use	As enrollments in introductory courses can exceed 1,000 students, the system must be highly scalable.
3) Cost	Exclusive use, Costs	In view of increasing budget restrictions, the system should be free for instructors and students.
4) Device	Clicker administration effort	Students and universities should not be required to buy clickers. Instead, a solution should integrate any available web-based infrastructure ("Bring-your-own-Device").
5) Installation	Installation, Configuration	Students and instructors should not be required to install any software on their devices.
6) OS	Installation	The artifact should be usable independently from the operating systems (OS) of the instructors' and the students' devices.

In Table 2 we list CRS providers and the mismatch of their solutions with a requirement. Note that some solutions fall short on several requirements. Due to space restrictions, we list each provider only once.

Table 2. Solution of Providers fall short of Requirements		
Requirement not fulfilled	**Providers**	**Comments**
Scale	Andy Schwen, Big nerd Ranch, Parallel Divergence Software, Polar Dynamics	restricted to 100, 64, 50, and 95 concurrent clients, respectively
Device	Audio General Inc., BeyondQuestions, Califone, ELMO, Fleetwood Group, IML, intellididact, isee, IVS, LearnStar, Option Technologies Interactive, PowerVote, QOMO HiteVision, Renaissance Learning, Sunsky Electronic, Texas Instruments	rely on radio frequency and dedicated physical clickers
	University of North Carolina, Wake Forest University	designed for pocket PCs
Installation	H-ITT, Turning Technologies, eInstruction, iRespond, iClicker, Meridia, Promethean, Qwizdom, and Smart	at least the instructor has to install software on her device
Cost	Learning Catalytics, Poll Everywhere, Textthemob, Go Education	
OS	Sergiy Krutykov	requires Microsoft Windows

None of the identified providers fulfill all requirements. Consequently, we decided to develop an alternative solution, the PINGO system.

Design of the Artifact

In the following, we briefly present the design of the artifact (more details can be found, e.g., in Sievers et al. 2012) and discuss several design choices as stipulated in the guidelines for design-based research (Hevner et al. 2004). In order to be as independent from the client OS as possible (cf. Requirement 6), we built the first implementation of the PINGO system as a website building on the *Ruby on Rails* framework (www.rubyonrails.org) (cf. Requirement 5). This open source framework was selected because of the

availability of many standard web application features, which enabled us to focus on implementing the core functionality. The goal to efficiently serve many concurrent users (cf. Requirement 2) in terms of response time and resource consumption led to an application design based on event-driven I/O (Pyarali et al. 1997). By so doing, according to the performance tests we ran, a high throughput and a constant response time can be achieved without the overhead of threading.

Figure 2. Backend Architecture
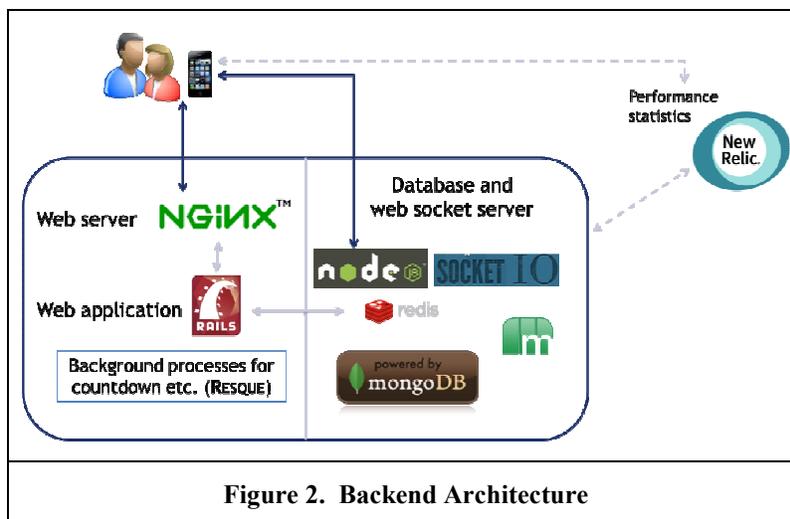
The compact data model contains entities for *users, lectures* with *polls* (these are the actual ConcepTests) and *options* with *votes*. The data model was designed according to the following requirements: First, *polls* in *lectures* and *options* in *polls* are dependent (weak) entities because they have no meaning independently from *lectures* and *polls*, respectively. Second, we require atomicity for operations on the data structures as there is a need for many concurrent writes (cf. Requirement 2). Using the document-oriented open source NoSQL database *MongoDB* (www.mongodb.org) avoids many multiple-table queries through the use of embedded object collections. Thus, the dependent entities are directly attached to their *container* without the need to fetch from a different table. Furthermore, MongoDB offers atomic *promised*[3] operations, such as atomic increments and atomic pushes to arrays, which we use for tracking of votes and voters. Furthermore, we integrated a *socket.io*-module to support WebSocket [4] communication with many concurrent clients. By running the PINGO application on top of this architecture, many concurrent users can be served efficiently and the application can be scaled, for example, using a computing cloud. Figure 2 illustrates the basic backend architecture.

In the web-based administrative interface instructors can set up *lectures*. To keep administrative load to a minimum and encourage usage of the prototype on a broad scale, setting up a *lecture* was designed to require just two mouse clicks. *Lectures* constitute the construct for instructors to collect ConcepTests that belong to one course. Once a *lecture* is created, instructors can instantly set up new ConcepTests. An instructor has to specify the question type, the number of possible answers and the duration of the poll (countdown timer). These settings can be remembered, thus enabling the instructor to ask the audience a new ConcepTest in the same format with one mouse click (cf. Requirement 1). ConcepTests can be prepared beforehand, but may also be set up "on the fly" during class. To support different didactical

---

[3] *promised* means that the application server sends a query to the database server, e.g., to increment a counter, and then immediately continues delivering the response to the client without waiting for a reply. This is possible because MongoDB promises to properly execute the command simply by receiving it. This increases performance and reduces complexity in an event-driven environment. For a performance comparison with SQL Server, see (Kennedy 2010).

[4] The *WebSocket API* is a feature of HTML5 enabling browsers to establish a persistent connection to a WebSocket server. Through this connection, messages between the browser and the server can be exchanged bidirectionally in real time (i.e., messages can be pushed to the client's browser).

approaches, it is not imperative to provide the poll's question or write out the answers in full in the PINGO application as this may also be done – at the instructor's discretion – in the medium used for presenting the lecture's content. Students can participate in the polls using any web-enabled device (cf. Requirement 3, 4, 5, and 6). To do so, they only need to join the channel for the current lecture by entering a four digit identification code. Once a student has joined a channel, new questions and other information are pushed to the client using WebSockets (cf. Requirement 1). The PINGO system automatically recognizes if a student accesses the poll using a mobile phone or a tablet. In this case, an optimized interface for her device is displayed. Participation in the poll is only possible during the pre-defined duration of the respective poll. To ensure this, we use WebSockets to synchronize the countdown timers of the clients.

Evaluation

We tested the technological features, usability and user acceptance of a first prototype of the PINGO system in a business information systems introductory course. This course was an ideal candidate for evaluating our prototype: it had over 1,000 enrolled students and 95% of these students possessed one or more web-enabled devices. According to ISO 9241, usability is defined as "*the extent to which intended users of a product achieve specified goals in an effective, efficient and satisfactory manner within a specified context of use.*" We adopted the system usability scale (SUS) (Brooke 1996) to measure the usability of our prototype. Mature, robust, and extensively used and adapted, it is a strongly recommended scale to measure usability (Zviran et al. 2006). Nevertheless, usability is only a necessary but not sufficient determinant of future usage. The most important challenge when introducing a new technology is to achieve user acceptance. In their seminal work, Davis (1989) proposed the Technology Acceptance Model (TAM) to predict user acceptance of IT. According to this model, the main predictors of technology acceptance are the constructs *perceived ease of use* (PEU) and *perceived usefulness* (PU). These constructs are both assumed to have a positive effect on the *behavioral intention to use* (BIU) the technology, which is closely related to the future system usage. The TAM was validated in many studies (e.g., Szajna 1996) and applied in numerous empirical settings (e.g., Koufaris 2002), amongst others, to predict the user acceptance of e-learning systems (e.g., Ong et al. 2004). Therefore, in addition to the SUS, we use these constructs as an important indicator for the evaluation of the PINGO system.

We tested the PINGO system in several sessions of a business information systems introductory course in the winter term 2011/2012. Participation in the prototype tests during the sessions was voluntary. On the technological level (stability, scalability to large groups etc.) all tests showed very satisfying results. To evaluate the usability and the user acceptance of our artifact, we handed out a paper-based questionnaire to the course participants after the first and the last test. The first questionnaire included standard constructs of the TAM: four items for PEU, six items for PU, and three items for BIU as well as some demographic questions. The second questionnaire was extended with ten SUS items. All items were measured on a seven point Likert scale. Both questionnaires are available on request from the authors.

On the day of the first test, 438 of the approximately 600 course participants who showed up completed the first questionnaire. Respondents were on average at the beginning of their second year of studies and the gender distribution was close to even (52% women, 48% men), mirroring the demographics of the whole population of enrolled students in this course. We take this as a weak indicator that our results are not biased through non-response by some groups of students. The second questionnaire was completed about six weeks later by 263 course participants[5]. By using control questions, 96 respondents of the first questionnaire and 57 respondents of the second questionnaire could be identified as answering without carefully reading the questions and had to be dropped. This leaves us with a final sample of 342 responses for the first and 206 responses for the second questionnaire.

For the quantitative assessment of our measurement model we followed standard psychometric scale-development procedures (Gerbing and Anderson 1988). In a first step we computed the item-to-total

---

[5] The lower response rate might be attributed to the late timing of our questionnaire distribution. Due to time restrictions during the lecture, course participants needed to stay on *after the end* of the lecture to complete the questionnaire.

correlation for each item and Cronbach's alpha for each factor. According to Bearden et al. (1989) items should have a corrected item-to-total correlation of at least 0.5. Following Nunally (1978) we required a minimum value of 0.7 for Cronbach's alpha. Subsequently, an exploratory factor analysis showed that the items for each construct load on only one factor. Additionally, we stipulated that each factor had to explain more than 50% of an item's variance. The results presented in Table 3 show that these criteria are met for each factor as well as for the entire set of our items. Furthermore, Table 3 reports summary statistics for each item. The first entry (second entry in brackets) in each cell shows the results from the first (second) questionnaire.

Table 3. Evaluation of Measurement Model and Summary Statistics (n=342(206))									
Construct	Item	Mean**	Standard Deviation**	Item to total correlation	Cronbach's alpha	Variance explanation of the first factor	T-value of factor loadings	Factor-reliability	Average variance extracted
PEU	PEU1	6.03 (6.45)	1.27 (1.11)	0.72 (0.88)	0.93 (0.96)	0.82 (0.89)	-*	0.89 (0.94)	0.66 (0.80)
	PEU2	6.36 (6.46)	1.19 (1.23)	0.85 (0.87)			17.26 (18.21)		
	PEU3	6.37 (6.52)	1.22 (1.15)	0.88 (0.91)			18.21 (22.49)		
	PEU4	6.46 (6.60)	1.12 (1.12)	0.86 (0.93)			18.17 (23.96)		
PU	PU1	4.66 (5.00)	1.46 (1.32)	0.79 (0.80)	0.94 (0.93)	0.77 (0.74)	-*	0.91 (0.90)	0.51 (0.55)
	PU2	5.08 (5.46)	1.48 (1.36)	0.86 (0.82)			20.48 (15.09)		
	PU3	5.43 (5.89)	1.61 (1.34)	0.72 (0.76)			16.02 (13.80)		
	PU4	4.70 (5.10)	1.44 (1.31)	0.88 (0.84)			21.21 (15.68)		
	PU5	5.33 (5.72)	1.40 (1.25)	0.85 (0.79)			20.60 (14.42)		
	PU6	4.96 (5.36)	1.45 (1.35)	0.82 (0.78)			19.11 (14.05)		
BIU	BIU1	5.88 (6.15)	1.45 (1.39)	0.89 (0.89)	0.94 (0.94)	0.89 (0.89)	-*	0.93 (0.93)	0.81 (0.82)
	BIU2	5.95 (6.23)	1.41 (1.35)	0.90 (0.89)			34.89 (23.63)		
	BIU3	5.57 (6.08)	1.52 (1.34)	0.82 (0.84)			24.38 (20.67)		

*Factor loadings of the first factor were standardized to 1
**Because all scales were measured with ordinal scales, caution should be used in interpreting means and standard deviations.

In a next step we subjected the data to a confirmatory factor analysis with the statistical package AMOS 19. For our measurement model χ^2/df (4.45, 3.46), GFI (0.89, 0.86), NFI (0.94, 0.93), CFI (0.95, 0.95), and RMSEA (0.10, 0.11) for the first (first value) and for the second questionnaire (second value) indicate an at least acceptable fit with the hypothesized measurement model. To prove convergence validity, we computed the average variance extracted and the factor reliability for each factor and tested the significance of each factor loading. To test for discriminant validity we conducted the test recommended by Fornell and Larcker (1981). The results of this test provide strong evidence of discriminant validity for the scales examined. We list the results of our confirmatory factor analysis in table 3. The correlation matrix for our constructs is available upon request from the authors.

In the next step we estimated the hypothesized model by structural equation modeling techniques using the AMOS 19 package. The computed values for χ^2/df (4.45, 3.46), GFI (0.89, 0.86), NFI (0.94, 0.93), CFI (0.95, 0.95), and RMSEA (0.10, 0.11) indicate an acceptable fit of the classical TAM for both questionnaires with the observed data. Confirming the predictions from the TAM, PU (standardized path coefficients: 0.40, 0.56) and PEU (standardized path coefficients: 0.50, 0.36) both have a significant (p<.001) positive effect on the BIU and explain more than 55% (60%) of the variance of this variable. Furthermore, as predicted by the TAM, PEU has a significant (p<.001) positive effect on PU (standardized path coefficients: 0.45, 0.48). As BIU is closely related to the future system usage (Venkatesh et al. 2003),

these results confirm the suggestion from the TAM literature that PU and PEU are important predictors of technology acceptance.

Besides testing the applicability of TAM in this context, we were also interested in the absolute values of the constructs. For our artifact, the average PEU was evaluated with 6.31 (7 indicating the maximum for all scales) and the average PU with 5.02 in the first questionnaire. Considering the positive effect of PEU and PU on BIU, both of these values indicate also a high value for BIU. An average value of 5.80 for BIU confirms this expectation. We find a similar pattern for the second questionnaire (PEU 6.51, PU 5.42, and BIU 6.15). All of these results are positive indicators for the future usage of the system. In addition, an aggregated SUS score of on average 72.5 out of 100 indicates a *good* usability of our prototype (Bangor et al. 2009). The quantitative evaluation of our prototype was accompanied by half-structured problem-centered interviews (Witzel 2000) to evaluate the didactical concept of the PINGO solution. Analogous to the quantitative results, the interview feedback was very positive. First results indicate particularly high potential for exam preparation, for student's self-evaluation in comparison with others, and for student's activation in large groups. Reassuringly, we also received positive personal feedback regarding the usage of the PINGO system from students enrolled in the course. These positive first evaluation results encourage us to further develop the PINGO system and to make it publicly available as open source in the near future.

Conclusion

In this research, we introduce a web-based open source solution that enables the transfer of the widely established PI approach to lectures with very large groups. The proposed solution avoids several existing technical flaws that appear to have hindered a more widespread adoption of PI. Evaluation results and personal feedback encourages us to further develop our prototype. While the focus in this contribution was mainly technology-driven, we are aware that any CRS solution is not beneficial by itself but is strongly contingent on how it is used on each occasion. We agree with Draper and Brown (2004) who conclude that technology is "*not essential to achieving learning or interactivity, which for millennia have been frequently achieved by other means; but nevertheless it makes the desired effect [...] easier to achieve more often, in more contexts, and with much less effort and attention. Thus the requirement to keep teachers' minds on the pedagogy not the technological means may in the end be the main argument for the technology, while also showing how important seamlessness and effortless operation may be to its ultimate effectiveness.*"

Consequently, there are two main directions for our future work in this area. First, the administration interface for instructors will undergo a redesign to reduce a number of usability problems that have been detected in the first tests. In addition, we will work on integrating new question types and providing enhanced visual analytics features for instructors to be better supported in their decisions. Second, we will work on the design of the didactical embedding for a range of scenarios. Most solutions offered in the CRS market focus primarily on the technical aspect. In PINGO we want to cater for scenarios to enable them to implement the PINGO system in a systematic didactical way. This would require an exploration of the methodological ways in which PI phases should be initiated and guided by the instructor. It is crucial for a successful learning process not only to let the learners talk to each other, but to help them to structure their discussion and provide information about how to work with each other in the peer discussion phases. Therefore, the impact of PI on communication structures and students' participation should also be evaluated in smaller learner groups (up to 50 students) with a more student-centered learning design. Moreover, instructors should be able to obtain valuable didactical support through the rich information on their courses gained from PINGO which would enable them to develop their curricula more effectively, and thus to improve their future lecturing. Finally, we plan to create didactical information tools to improve both the technical and the learning processes.

References

Bangor, A., Kortum, P., and Miller, J. 2009. "Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale*," Journal of Usability Studies* (4:3), pp. 114-123.

Barber, M. and Njus, D., 2007. "Clicker Evolution: Seeking Intelligent Design," *CBE—Life Sciences Education* (6), pp. 1-20.

Bearden, W., Netemeyer, R., and Teel, J. 1989. "Measurement of Consumer Susceptibility to Interpersonal Influence," *Journal of Consumer Research* (15:4), pp. 473-481.

Beichner, R.J., Saul, J. M., Allain, R. J., Deardorff, D. L., and Abbott, D. S. 2000. "Introduction to SCALE-UP: Student-centered activities for large enrollment university physics," in *Proceedings of the 2000 Annual Meeting of the American Society for Engineering Education*, Session 2380.

Boyle, J. T., and Nicol, D. J. 2003. "Using classroom communication systems to support interaction and discussion in large class settings," *Association for Learning Technology Journal* (11:3), pp. 43-57.

Brooke, J. 1996. "SUS: a 'quick and dirty' usability scale," in *Usability Evaluation in Industry*, P. W. Jordan, B. Thomas, B. A. Weerdmeester, and A. L. McClelland (eds.), London: Taylor and Francis.

Brooks, B., and Koretsky, M. 2011. "The Influence of Group Discussion on Students' Responses and Confidence during Peer Instruction," *Journal of Chemical Education* (88), pp. 1477-1484.

Butchart, S., Handfield, T., and Restall, G. 2009. "Teaching Philosophy, Logic and Critical Thinking using Peer Instruction," *Teaching Philosophy* (32:1), pp. 1-40.

Caldwell, J. E. 2007. "Clickers in the Large Classroom: Current Research and Best-Practice Tips," *CBE—Life Sciences Education* (6:1), pp. 9-20.

Cleary, A. 2008. "Using Wireless Response Systems to Replicate Behavioral Research Findings in the Classroom," *Teaching of Psychology* (35), pp. 42-44.

Cortright, R. N., Collins, H. L., and DiCarlo, S. E. 2005. "Peer instruction enhanced meaningful learning: ability to solve novel problems," *Advances in Physiology Education* (29), pp. 107-111.

Crouch, C.H., and Mazur, E. 2001. "Peer instruction: Ten years of experience and results, "*American Journal of Physics* (69), pp. 970-977.

Crouch, C.H., Watkins, J., Fagen, A. P., and Mazur, E. 2007. "Peer Instruction: Engaging Students One-on-One, All At Once," in *Reviews of Research-Based Reform Curricula in Introductory Physics*, E. F. Redish, and P. Cooney (eds.) Reviews in PER Vol. 1.

Davis, F. D. 1989. "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology," *MIS Quarterly* (13:3), pp. 319-340.

DeCorte, E. 1996. "New perspectives on learning and teaching in higher education," in *Goals and Purposes of Higher Education*, Burgen, A. (ed.), London: Jessica Kingsley

Draper, S. W., and Brown, M. I. 2004. "Increasing interactivity in lectures using an electronic voting system," *Journal of Computer Assisted Learning* (20), pp. 81–94.

Dufresne, R. J., Gerace, W. J., Leonard, W. J., Mestre, J. P., and Wenk, L. 1996. "Classtalk: a classroom communication system for active learning," *Journal of Computing in Higher Education* (7), pp. 3-47.

Fagen, A. P., Crouch, C. H., and Mazur, E. 2002. "Peer instruction: Results from a range of classrooms," *Physics Teacher* (40), pp. 206-209.

Fagen, A. P. 2003. Assessing and Enhancing the Introductory Science Course in Physics and Biology: Peer Instruction, Classroom Demonstrations, and Genetics Vocabulary, Thesis, Harvard University Cambridge, Massachusetts.

Feeley, M. 2012. "The Impact of Peer Instruction Pedagogy and Clicker Technology On Student Learning and Attitudes Toward Learning in a Large Upper-Division Political Science Course," *APSA Teaching and Learning Conference*, Washington, D.C., USA.

Fies, C., and Marshall, J. 2006. "Classroom Response Systems: A Review of the Literature," *Journal of Science Education and Technology* (15:1), pp. 101-109.

Fornell, C., and Larcker, D. 1981. "Evaluating Structural Equation Models with Unobservable Variables and Measurement Errors," *Journal of Marketing Research* (18:1), pp. 39-51.

Gerbing, D., and Anderson J. (1988) "An Updated Paradigm for Scale Development Incorporating Unidimensionality and Its Assessment," *Journal of Marketing Research*, Vol. 25 No. 2, pp. 186-192.

Giuliodori, M. J., Lujan, H. L., and DiCarlo, S. E. 2006. "Peer instruction enhanced student performance on qualitative problem-solving questions," *Advances in Physiology Education* (30), pp. 168-173.

Grainger, S., Kestell, C., and Willis, C. 2011. "Staff and student perceptions of the effective use of contemporary lecture theatre technology," *Proceedings of the 22nd Annual Conference for the Australasian Association for Engineering Education* 5-7 December 2011, Fremantle, Australia, pp. 607-611.

Hake, R. R. 1998. "Interactive engagement versus traditional methods: a six-thousand student survey of mechanics test data for introductory physics courses," *American Journal of Physics* (66), pp. 64-74.

Herreid, C. F. 2006. "'Clicker' Cases: Introducing Case Study Teaching Into Large Classrooms," *Journal of College Science Teaching* (36:2), pp. 43-47.

Hevner, A.R., March, S.T., Park, J., and Ram, S. 2004. "Design science in information systems research," *MIS Quarterly* (28:1), pp.75-105

Judson E., and Sawada, D. 2002. "Learning from Past and Present: Electronic Response Systems in College Lecture Halls," *Journal of Computers in Mathematics and Science Teaching* (21:2), pp. 167-181

Kay, R. H., and LeSage, A. 2009a. "Examining the benefits and challenges of using audience response systems: A review of the literature," *Computers & Education* (53:3), pp. 819-827.

Kay, R. H., and LeSage, A. 2009b. "A strategic assessment of audience response systems used in higher education," *Australasian Journal of Educational Technology* (25:2), pp. 235-249.

Kennedy, M. 2010. MongoDB vs. SQL Server 2008 Performance Showdown, available at: http://blog.michaelckennedy.net/2010/04/29/mongodb-vs-sql-server-2008-performance-showdown/

Koufaris, M. 2002. "Applying the technology acceptance model and flow theory to online consumer behavior," *Information Systems Research* (13:2), pp. 205-223.

Lantz, M. E. 2010. "The use of 'clickers' in the classroom: Teaching innovation or merely an amusing novelty?," *Computers in Human Behavior* (26:4), pp. 556-561.

Lasry, N. 2008. "Clickers or Flashcards: Is There Really a Difference?," *The Physics Teacher* (46), pp. 242-244.

Lasry, N., Mazur, E., and Watkins, J. 2008. "Peer Instruction: from Harvard to the Two-year College," *American Journal of Physics* (76:11), pp. 1066-1069.

MacArthur J. R., and Jones, L. L. 2008. "A review of literature reports of clickers applicable to college chemistry classrooms," *Chemistry Education Research and Practice* (9:3), pp. 187-195.

Mazur, E. 1997a. Peer Instruction: A User's Manual. Englewood Cliffs, NJ: Prentice-Hall.

Mazur E. 1997b. "Peer instruction: getting student to think in class," in *The Changing Role of Physics Departments in Modern Universities*, E. F. Redish, and J. S. Rigden. Buenos Aires, Argentina, pp. 981-988.

Miller, R. L., Santana-Vega, E., and Terrell, M. S. 2006. "Can Good Questions and Peer Discussion Improve Calculus Instruction?," *PRIMUS: Problems, Resources, and Issues in Mathematics Undergraduate Studies* (16:3), pp. 193-203.

Moss, K., and Crowley, M. 2011. "Effective learning in science: The use of personal response systems with a wide range of audiences," *Computers & Education* (56:1), pp. 36-43.

Nicol, D. J., and Boyle, J. T. 2003. "Peer Instruction versus Class-wide Discussion in Large Classes: a comparison of two interaction methods in the wired classroom," *Studies in Higher Education* (28:4), pp. 457-473.

Nunally, J. 1978. *Psychometric Theory.* 2nd Edition, McGraw Hill, New York.

Ong, C., Lai, J., Wang, Y. 2004. "Factors affecting engineers' acceptance of asynchronous e-learning systems in high-tech companies," *Information & Management* (41:6), pp. 795-804.

Patry, M. 2009. "Clickers in Large Classes: From Student Perceptions Towards an Understanding of Best Practices," *International Journal for the Scholarship of Teaching and Learning* (3:2), pp. 1-11.

Pilzer, S. 2001. "Peer instruction in physics and mathematics," *PRIMUS: Problems, Resources, and Issues in Mathematics Undergraduate Studies* (11:2), pp. 185-192.

Porter, L., Lee, C., Simon, B., and Zingaro, D. 2011a. "Peer Instruction: Do Students Really Learn from Peer Discussion in Computing?," *Proceedings of the 7th International Workshop on Computing Education Research* (ICER'11), Providence, USA.

Porter, L., Lee, C., Simon, B., Cutts, Q., and Zingaro, D. 2011b. "Experience Report: A Multi-classroom Report on the Value of Peer Instruction," *Proceedings of the 16th Annual Conference on Innovation and Technology in Computer Science Education* (ITiCSE'11), Darmstadt, Germany.

Pyarali, I., Harrison, T., Schmidt, D., Jordan, T. 1997. "Proactor: An Object Behavioral Pattern for Demultiplexing and Dispatching Handlers for Asynchronous Events," *4th Annual Pattern Languages of Programming Conference*, Allerton Park, Illinois.

Rao, S. P., and DiCarlo, S. E., 2000. "Peer Instruction improves Performance on Quizzes," *Advances in Physiology Education* (24:1), pp. 51-55.

Roschelle, J., Penuel, W. R., and Abrahamson, L. 2004. "Classroom Response and Communication Systems: Research Review and Theory," *Annual Meeting of the American Educational Research Association*, San Diego, CA, 2004.

Salemi, M. K. 2009. "Clickenomics: Using a Classroom Response System to Increase Student Engagement in a Large-Enrollment Principles of Economics Course," *Journal of Economic Education* (40:4), pp. 385-404.

Schmidt, B. 2011. "Teaching engineering dynamics by use of peer instruction supported by an audience response system," *European Journal of Engineering Education* (36:5), pp. 413-423.

Sievers, M., Reinhardt, W., Kundisch, D., and Herrmann, P. 2012. "Developing electronic classroom response apps for a wide variety of mobile devices – Lessons learned from the PINGO project," *Proceedings of the 11th World Conference on Mobile and Contextual Learning* (mLearn), 16-18th October, Helsinki, Finland.

Simon, B., Kohanfars, M., Lee, J., Tamayo, K., and Cutts, Q. 2010. "Experience report: peer instruction in introductory computing," *Proceedings of the 41st ACM Technical Symposium on Computer Science Education* (SIGCSE '10), ACM, New York, NY, USA, pp. 341-345.

Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., and Su, T. T. 2009. "Why peer discussion improves student performance on inclass concept questions," *Science* (323), pp. 122-124.

Stowell, J. R., and Nelson, J. R. 2007. "Benefits of Electronic Audience Response Systems on Student Participation, Learning, and Emotion," *Teaching of Psychology* (34:4), pp. 253-258.

Stuart, S. A. J., Brown, M. I., and Draper, S. W. 2004. "Using an electronic voting system in logic lectures: one practitioner's application," *Journal of Computer Assisted Learning* (20), pp. 95-102.

Szajna, B. 1996. "Empirical evaluation of the revised technology acceptance model," *Management Science* (42:1), pp. 85-92.

Turpen, C., and Finkelstein, N. D. 2009. "Not all interactive engagement is the same: Variations in physics professors' implementation of Peer Instruction," *Physical Review Special Topics - Physics Education Research* (5:2), pp. 020101 1-18.

Turpen, C., and Finkelstein, N. D. 2010. „The construction of different classroom norms during Peer Instruction: Students perceive differences," *Physical Review Special Topics - Physics Education Research* (6:2), pp. 020123 1-22.

Venkatesh, V., Morris, M. G., Davis G. B., and Davis, F. D. 2003. "User Acceptance of Information Technology: Toward a Unified View," *MIS Quarterly* (27:3), pp. 425-478.

Witzel, A. 2000. "The Problem-centered Interview," *Forum Qualitative Social Research* (1:1), Art. 22.

Zingaro, D. 2010. "Experience report: Peer instruction in remedial computer science," *Proceedings of the 22nd World Conference on Educational Multimedia, Hypermedia & Telecommunications*, Toronto, Canada.

Zviran, M., Glezer, C., and Avni, I. 2006. "User Satisfaction from Commercial Web Sites: The Effect of Design and Use," *Information and Management* (43:2), pp. 157-178.