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Just enough, but not too much interactivity leads to better clinical skills performance after a computer assisted learning module

A. Kalet, MPH, MD^{1,2}, H.S. Song, PhD^{3,4}, U.S. Sarpel, MSc, MD⁵, R. Schwartz, PhD⁴, J. Brenner, MD^{2,6}, T.K Ark, MS², and J. Plass, PhD⁴

¹Division of Educational Informatics (DEI), New York University School of Medicine

²Division of General Internal Medicine, Department of Medicine, New York University School of Medicine

³Department of Teacher Education, School of Education, Georgian Court University

⁴CREATE, Steinhardt School of Culture, Education, and Human Development, New York University

⁵Department of Surgery, Mount Sinai School of Medicine

⁶Hofstra North-Shore LIJ School of Medicine

Abstract

Background—Well-designed computer-assisted instruction (CAI) can potentially transform medical education. Yet little is known about whether specific design features such as direct manipulation of the content yield meaningful gains in clinical learning. We designed three versions of a multimedia module on the abdominal exam incorporating different types of interactivity.

Methods—As part of their physical diagnosis course, 162 second-year medical students were randomly assigned (1:1:1) to Watch, Click or Drag versions of the abdominal exam module. First,

Corresponding author: Adina Kalet, MD, MPH, 550 First Avenue, BCD, D401, New York, NY 10016, Tel: 212.263.1137, Fax: 212.263.8234, adina.kalet@nyumc.org.

Declaration of Interest

The authors report no declarations of interest.

Notes on contributors:

Adina L. Kalet, MPH, MD: Professor of Medicine and Surgery, Division of Educational Informatics (DEI), Division of General Internal Medicine, New York University School of Medicine

Hyuksoon S. Song, PhD: Junior Research Scientist, Steinhardt School of Culture, Education, and Human Development, New York University at the time this work was completed. Now he moved to Georgian Court University to serve as Assistant Professor of Education.

Umut Sarpel, MSc, MD: Assistant Professor of Surgery, Department of Surgery, New York University School of Medicine at the time this work was completed. Now she is with the Department of Surgery, Mount Sinai School of Medicine

Ruth Schwartz, PhD: Junior Research Scientist, Steinhardt School of Culture, Education, and Human Development, New York University

Judy Brenner, MD: Senior Associate Director of Internal Medicine Residency Program, Department of Medicine, New York University School of Medicine at the time this work was done. Now Assistant Dean for Curricular Integration at Hofstra North-Shore LIJ School of Medicine

Tavinder K. Ark, MS: Research Associate, Division of General Internal Medicine, New York University School of Medicine at the time this work was completed. Now a Senior Research Scholar and doctoral student in The Measurement, Evaluation, and Research Methodology (MERM) program at University of British Columbia.

Jan Plass, PhD: Professor of Educational Communication and Technology, Steinhardt School of Culture, Education, and Human Development, New York University

students' prior knowledge, spatial ability, and prior experience with abdominal exams were assessed. After using the module, students took a posttest; demonstrated the abdominal exam on a standardized patient; and wrote structured notes of their findings.

Results—Data from 143 students were analyzed. Baseline measures showed no differences among groups regarding prior knowledge, experience, or spatial ability. Overall there was no difference in knowledge across groups. However, physical exam scores were significantly higher for students in the Click group.

Conclusions—A mid-range level of behavioral interactivity was associated with small to moderate improvements in performance of clinical skills. These improvements were likely mediated by enhanced engagement with the material, within the bounds of learners' cognitive capacity. These findings have implications for the design of CAI materials to teach procedural skills.

Introduction

Physical examination is a key aspect of patient-physician interactions and a valuable component of accurate clinical diagnosis. However, the physical exam skills of new physicians are declining, and many barriers to the effective teaching of these critical procedural skills have been identified (Ramani 2008). Computer assisted instruction (CAI), an immensely scalable approach, has the potential to address some of these barriers, including lack of standardized curriculum, inadequately directed experiential learning, and insufficient numbers of appropriate teachers (Ramani 2008). Well-designed CAI has been shown to be effective in producing lasting clinical skills (Criley et al. 2008; Jang et al. 2005; Schneider et al. 2006), yet the literature provides little guidance on the relative advantages of specific instructional and technical design features to maximize learning. Given the rapidly expanding use of CAI in medical education and the potentially high cost of development, such resource-conserving guidance is critical.

Learning theory strongly supports the proposition that interactive multimedia environments can enhance knowledge acquisition and motivation to learn (Mayer & Chandler 2001; Moreno & Mayer 2005). Wittrock's theory of generative learning (Wittrock 1974) argues that comprehension depends on the learner's active construction of connections when learning new concepts or facts. Dual-coding theory (Clark & Paivio 1991) suggests that encoding information in memory through the use of multiple modalities, including visual, verbal and non-verbal (e.g. visual and haptic), results in multiple opportunities for retrieval. The multimodal theory of memory (Engelkamp & Zimmer 1994) also stresses the importance of motor activity in encoding and retrieval of information. Research suggests that providing learners with tools that enable them to actively manipulate learning content through behavioral engagement, such as by dragging objects or adjusting sliders, can cognitively engage them in a process of active learning and construction of knowledge (Domagk et al. 2010; Plass et al. 2009; Wittrock 1974). One recent study has compared the effects of different types of interactivity (passive watching, moving objects by clicking them, and dragging objects) and has found that more action phrases are recalled when learners can perform the specified action by dragging the corresponding object on the screen than any of the other options (Schwartz, 2010). However, cognitive load theory warns that the capacity of working memory is limited (Plass et al. 2010; Pollock et al. 2002), and some research suggests that too much control and choice may lead to high cognitive load and, as a result, decreased learning (Adler & Johnson 2000).

In addition, although hands-on manipulation is regarded as a key element in clinical education, empirical studies on interactive multimedia materials for the teaching of medical content do not address the type of activity performed by the user, focusing instead on the

broader issue of interactivity vs. absence of interactivity (Cook et al. 2010) or specific learning strategies such as self-assessment (Cook et al. 2006) and feedback (Kopp et al. 2008). Therefore, this study examined the effects of specific types of content manipulation on learning of physical exam skills in an online educational environment. The degree of clinical knowledge acquisition and level of performance is compared for three types of content manipulation: Watch, Click, and Drag. We hypothesized that escalating degree of interactivity would correlate with higher levels of knowledge acquisition, and/or performance of physical exam skills. Our primary outcome measure was improvement of knowledge as measured by post-test scores. Our secondary outcome was physical exam skills as measured by a standardized patient evaluation and accuracy of diagnosis of a mock case.

Methods

Participants

After obtaining approval from the Institutional Review Board, 162 second-year medical students at a large private medical school in the northeastern United States were evaluated for study participation. All students were assigned to use an online instructional module on performing an abdominal exam as a part of the required “Introduction to Bedside Diagnosis” course. The module presented the steps involved in performing an abdominal exam, including specific maneuvers to be performed, information on what might be expected in a typical exam, and indications of an abnormal exam.

After hearing a brief description of the study, the students completed an online consent form. Consenting students were randomly assigned to one of three conditions (Watch, Click, and Drag). Out of 162 students, 152 students (93.82%) consented to participate in the study. Data from nine students in the Watch condition were lost due to technical problems, leaving 143 students in the final analysis (Watch: 42; Click: 51; Drag: 50).

Learning Materials

A computer-based multimedia presentation, targeted at second-year medical students, was developed to teach proper procedure for an abdominal examination. The online module included a 20-minute case-based presentation on a structured approach to the examination (Introduction, Inspection, Auscultation, Palpation, Percussion, and Additional Maneuvers). Three content equivalent versions of the practice sections following the presentation were designed to allow differing types of active content manipulation: Watch, Click and Drag. Users in the Watch condition controlled only the pace of the presentation; they were provided only with simple stop-and-go functionality. In the Click condition, students used the mouse to trigger animated demonstrations; for example, clicking on a stethoscope tool began a demonstration of the auscultation step (listening for sounds). Those in the Drag condition were able to click and drag tools in motions simulating actual performance of the task (e.g., moving the stethoscope over different quadrants of the patient’s abdomen, as represented in the computer graphic). Figure 1 shows a screenshot from the Click version of the instructional module.

Measures

Spatial ability (Spatial relations) test—Spatial ability has been found to be a predictor of success in multimedia learning environments and is therefore an important covariate in this study (Garg et al. 2001; Leutner & Kretschmar 1988; Plass et al. 2003). To assess the spatial relations sub-factor of spatial ability, participants were asked to complete the paper-and-pencil Card Rotation Test from the *Manual for Kit of Factor-Referenced Cognitive Tests* (Ekstrom et al. 1976).

Knowledge pre-test—A 17-item multiple-choice test of basic factual knowledge, developed by content experts, was administered to measure participants' prior knowledge of the abdominal examination. Internal consistency for the knowledge pre-test was evaluated using Cronbach's alpha coefficient, $\alpha = .476$.

Prior experience survey—A 3-item survey asked how often participants had previously performed an abdominal examination in an educational or professional setting. This survey used a 5-point Likert scale ranging from 1 (never) to 5 (10 times or more).

Knowledge post-test—An 18-item multiple-choice procedural knowledge test was administered to assess participants' post-treatment knowledge of the abdominal examination. Items on the knowledge post-test were; developed by content experts, differed from items of the knowledge pre-test, covered content across all sections of the instructional module and had an internal consistency measured by Cronbach's alpha coefficient of .340.

Standardized patient checklist—Following the online module, each participant conducted an abdominal examination on a standardized patient (SP), an actor portraying a patient with acute appendicitis. These rigorously trained SPs assessed students' procedural performance using a 17-item behaviorally anchored checklist, rating the extent to which each participant accurately completed each step of the abdominal examination (not done, partially done, well done). The reliability coefficient alpha for the checklist was .685.

Patient note—Participants were asked to write down their findings immediately after the physical examination with a standardized patient. This patient note was a one-page sheet with sections for the relevant chief complaint, history, physical exam, differential diagnosis and next steps. The score on the patient note was calculated by dividing the number of correct diagnoses by the total number of diagnoses they listed in the note.

Degree of Interaction with the interface—To examine whether the degree of interaction with the module differed depending on the type of content manipulation we measured time-on-task using computer log data. Degree of interaction was operationalized as time-on-task in seconds for each step in the module.

Procedures

This study was conducted as part of the Introduction to Bedside Diagnosis (IBD) curriculum, a required second-year course. Eight sections of the class, ranging in size from 20 to 22 students, were conducted, each lasting 80 minutes.

The first part of each section, during which students used the instructional module, took place in a computer-equipped classroom. Upon entering the room, students were assigned to one of the 3 conditions based on sequential log-in numbers.

After a brief introduction to the study, participants completed the test of spatial ability, prior knowledge test, and prior experience survey. They then used the online abdominal examination module and completed the knowledge post-test.

Each participant then moved individually to another room and was given 10 minutes to complete an abdominal examination on a SP. After the examination, participants were asked to document their findings in a patient note. Soon after this session participants received the knowledge test with correct answers and a copy of their SP interaction checklist.

Data Analysis

Data was entered and analyzed using SPSS ® Version 18. Data were summarized in means and standard deviations. To examine the effects of condition on knowledge acquisition and physical exam skills performance we first conducted ANCOVAs with knowledge pre-test and spatial ability test scores as covariates. Because we found no significant impact of the covariates on outcomes we choose to report the results of one-way analyses of variance (ANOVA) since it preserves degrees of freedom, is simplest to understand and the results are the same. A priori alpha level was set as .05 for all estimations. Partial eta-squares (η^2p) are reported to assess effect size (proportion of variance in student performance accounted for by the 3 levels of conditions-Watch, Click, Drag) and Cohen's d, the standardized difference, were calculated on pairs of means identified by the Tukey's post-hoc test. We do both because, partial eta squared is interpretable only in the context of this study and the Cohen's d allows comparison of the effect size across studies and meta-analyses (Cohen, 1988; Hattie & John, 2009).

Results

Clinical knowledge acquisition and performance

Table 1 presents participants' prior experience with abdominal examination, prior knowledge and spatial ability at baseline. Overall, 65 (45.5%) students had no prior experience with abdominal examinations. The average prior knowledge test score was 5.8 correct out of 17, suggesting that most students were novices in this domain. There was no initial difference in prior experience among students in the three conditions, $\eta^2(2) = 0.37$, $p = .83$; prior knowledge, $F(2, 140) = 0.44$, $p = .64$; or spatial relations ability, $F(2, 125) = 2.14$, $p = .12$.

There was no significant effect of condition on knowledge acquisition, measured by the knowledge post-test. However, there was a significant effect of condition on physical exam skills performance measured by the SP, $F(2, 138) = 3.33$, $P < .05$, $\eta^2p = .046$. Tukey's post-hoc test revealed that students in the Click condition showed better physical exam skills performance than those in the Drag condition (difference = .07, 95% CI: .00 ~ .18, Cohen's $d = .39$, small to medium effect). Table 2 shows mean scores and standard deviations for the three conditions on the knowledge post-test and the physical examination.

When students' physical exam performance was further broken down into the steps of the abdominal examination, there was a significant effect of condition for three of the steps: Auscultation, $F(2, 138) = 4.34$, $P < .05$, $\eta^2p = .060$; Palpation, $F(2, 138) = 3.61$, $P < .05$, $\eta^2p = .050$; and Additional Maneuvers, $F(2, 138) = 3.90$, $P < .05$, $\eta^2p = .053$. Tukey's post-hoc test revealed that in the Auscultation step, students in the Click condition showed significantly better performance than those in the Watch condition (difference = .50, 95% CI: .03 ~ .48, Cohen's $d = .55$, medium effect); students in the Click condition significantly outperformed students in the Drag condition for Palpation (difference = .15, 95% CI: .01 ~ .30, Cohen's $d = .26$, small effect) and Additional Maneuvers (difference = .20, 95% CI: .02 ~ .38, Cohen's $d = .53$, medium effect).

Based on patient notes, more students in the Drag (92.3%) and the Click conditions (89.8%) correctly diagnosed a SP as having appendicitis than students in the Watch condition (81.0%). The 10.3% difference between the Drag and Watch conditions was statistically significant, $t(87) = 2.62$, $p < .05$, Cohen's $d = .55$, moderate to large effect.

Interaction with interface

We further examined whether the degree of interaction with the module differed depending on the type of content manipulation. Due to technical problems, data from one student in each of the Click and Drag conditions were lost.

Table 3 summarizes the degree of students' interaction, by step of the physical exam of the abdominal examination, depending on condition.

There was a significant difference in total time-on-task, measured in seconds, depending on condition, $F(2, 138) = 7.97$, $P < .001$, $\eta^2 p = .104$. Tukey's post-hoc test showed that students in the Click and Drag conditions spent more time on the learning task than students in the Watch condition (difference 209.79 (3.5 minutes), 95% CI: 84.38 ~ 335.07 for Click; difference 135.65 (2.25 minutes), 95% CI 9.22 ~ 261.07 for Drag). There was no significant difference between the Click and Drag conditions.

When steps of the abdominal examination were examined in detail, there were significant differences among conditions in the time-on-task for three of the steps: Inspection, $F(2, 138) = 71.67$, $P < .001$, $\eta^2 p = .509$; Auscultation, $F(2, 138) = 4.26$, $P < .05$, $\eta^2 p = .058$; and Palpation, $F(2, 138) = 3.34$, $P < .05$, $\eta^2 p = .046$.

According to Tukey's post-hoc tests, students in the Click condition spent more time on Inspection than those in Watch and Drag conditions (difference= 147.51 (2.5 minutes) 95% CI: 115.71 ~ 179.56 for Watch; difference= 122.37 (2.0 minutes) 95% CI 91.70 ~ 153.02 for Drag), and students in the Drag condition stayed longer on Auscultation (difference= 38 (.64 minute) 95% CI: 7.18 ~ 69.23) and Palpation (difference= 55 (.92 minutes) 95% CI: 7.80 ~ 34.06) than those in the Watch condition.

Discussion and Educational Significance

Our study showed that in a multimedia-learning environment designed to teach physical exam skills, type of content manipulation influenced the clinical performance of novice medical students. However, the results are complex and not entirely as hypothesized.

We anticipated that greater relevant behavioral interactivity would be associated with the more learning. Therefore, students in the Drag condition, who manipulated the material in the most authentic way, were expected to outperform students in the Click condition and both would outperform the more passive Watch condition. However, although students in Click and Drag conditions had more opportunities to initiate actions and spent more time-on-task, there were no significant differences among conditions on the computer-based test of knowledge. It is unlikely that this negative finding is a consequence of a "ceiling effect" in knowledge attainment since there was room for improvement. The mean post-test performance for all students was 78% correct (14/18 questions). However, the low internal consistency of this measure suggests that the test itself may not be a reliable indicator of learning outcomes

We found small to moderate differences in performance of the abdominal examination on a SP, with students in the Click condition outperforming both other conditions. Overall students assigned to the Click condition spent 3.5 minutes (26%) more time-on-task than those in the Watch and 1.24 minutes (13.5%) more than those in the Drag condition. In a meta-analysis, Cook et al. (2010) showed that higher levels of interactivity are associated with more time-on-task, which in turn was correlated with knowledge outcomes. Also McGaghie et al (2006) demonstrated that there is a strong association between hours of practice on simulation and learning outcomes. Interestingly, 50% of the variance among conditions was accounted for by the fact that the students in the Click condition spent the

majority of the extra time in the Inspection section of the module but they performed better on the auscultation, palpation and advanced maneuvers components of the exam. We believe that this is because the Click condition captured the students attention early the module, forcing them to slowed down and engage with the material more intently than the Watch condition.

To interpret these findings further, the differences between the Dragging and Clicking modes must be carefully considered. Both modes required detailed attention to the instructional material as well as significant student activity. In the Click condition, students interacted simply by clicking on appropriate tools. The Drag condition required students to systemically engage in more complex interactions, dragging the tools in motions simulating performance of the abdominal exam. It may be that for a complex content area such as physical exam skills, the cognitive resources required to perform the more complicated interactions were so high that they distracted students from processing the content. The simpler interactions required in the Click condition may have promoted cognitive engagement without extraneous distractions caused by behavioral engagement (Domagk et al. 2010). These findings are consistent with research showing that cognitive resources required to process the learning materials compete with resources required by the interaction with the material for the same limited available working memory (Plass et al. 2010). Other studies have found that high levels of interactivity and control may be cognitively demanding and of benefit only in specific contexts (Keehner, Hegarty, Cohen, Khooshabeh, & Montello, 2008; Park, Lee, & Kim, 2009; Schnotz, Böckheler, & Grzondziel, 1999; Schwaborn, Thillmann, Opfermann, & Leutner, 2011; Stull & Mayer, 2007).

Results also showed that students in the conditions offering more interactive opportunities, i.e., Click and Drag conditions, were more likely to accurately identify the patient's diagnosis as acute appendicitis on the patient note. Given that the case shown in the module was consistent with this diagnosis and that the SP presented similar symptoms, we were not surprised that most students were able to come to the correct conclusion. In contrast, the lack of engagement for some of the student in the Watch group seems to have led those students to miss these fairly obvious connections. This finding indicates that too little engagement with materials through both low behavioral interactivity and less time-on-task, which can be interpreted as low cognitive activity, such as in our 'Watch' condition, may result in reduced learning.

As is the case for all empirical studies, our study has limited generalizability. Due to technical problems unrelated to the particular condition, data from nine students in the Watch condition were lost, resulting in a reduced sample size in this one arm of the trial that reduced the power to detect meaningful differences that may have existed. The low Cronbach's alpha observed for the knowledge test indicated a low reliability of this outcome measure, which may explain the fact that this measure was not able to detect a difference in knowledge acquisition among the groups. It is reassuring that clinically meaningful effects on skills performance were demonstrated though the SP and patient notes.

Our findings support the use of computer-assisted materials to teach skills such as the physical exam and suggest that careful attention to designing interactive features has the potential to enhance educational effectiveness in important ways. Cognitive load theory posits that good instructional design minimizes extraneous sources of load on active working memory so that learners can apply their limited cognitive resources to the processing of the material, especially when, due to its immutable complexity, this material itself induces a high intrinsic cognitive load. Good instructional design in this case provides only relevant material, presents it simply using both words and images which are not redundant, and assists learners by helping them to process the material, i.e., to construct and

automate schemata for the new material. Our findings suggest that the Click condition had the optimal balance of intrinsic and extraneous load, and of behavioral and cognitive engagement, for this content: students were lead through a simple rehearsal of the motor actions needed to conduct the exam while still having available the cognitive capacity to learn related material (e.g., How should the findings of the exam be interpreted? When should additional maneuvers be performed?). Students in the Watch version were not cognitively engaged enough to learn the procedure the cognitive demands were too low. Students in the Drag condition, on the other hand, may have been distracted by the need to apply significant cognitive resources to behavioral engagement, i.e., manipulating the mouse, especially for difficult-to-simulate maneuvers such as palpation.

Conclusion

Well-designed Computer Assisted Instruction (CAI) has the potential to transform medical education but is currently not achieving its full potential (Cook & Triola 2009), in part due to the dearth of research on CAI design features. In particular, those design features that allow students to actively manipulate content could well yield meaningful gains in clinical learning. In the present study we found that a mid-range, simple form of behavioral interactivity, maximized improvements in performance of clinical skills, suggesting an identifiable “sweet spot” for designing effective CAI experiences. The type of interactivity had no detectable impact on knowledge acquisition, which was good for all conditions. The improvements in clinical skills were likely mediated by learners’ enhanced engagement with the material in a way that did not distract from the processing of the information. These findings are consistent with theories of multimedia learning and the cognitive load theory, and provide guidance for the design of CAI materials to teach procedural skills.

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References

- Adler M, Johnson K. Quantifying the literature of computer-aided instruction in medical education. *Acad Med.* 2000; 75(10):1025–1028. [PubMed: 11031152]
- Clark JM, Paivio A. Dual coding theory and education. *Educ Psychol Rev.* 1991; 3(3):149–210.
- Cohen, J. Statistical power analysis for the behavioral sciences. 2. Hillsdale, NJ: Lawrence Erlbaum; 1988.
- Cook DA, Levinson AJ, Garside S. Time and learning efficiency in internet-based learning: A systematic review and meta-analysis. *Adv Health Sci Educ.* 2010; 15(5):755–770.
- Cook DA, Levinson AJ, Garside S, Dupras DM, Erwin PJ, Montori VM. Instructional design variations in internet-based learning for health professions education: A systematic review and meta-Analysis. *Acad Med.* 2010; 85(5):909–922. [PubMed: 20520049]
- Cook DA, Thompson WG, Thomas KG, Thomas MR, Pankratz VS. Impact of self-assessment questions and learning styles in web-based learning: A randomized, controlled, crossover trial. *Acad Med.* 2006; 81(3):231–238. [PubMed: 16501263]
- Cook DA, Triola MM. Virtual patients: A critical literature review and proposed next steps. *Med Educ.* 2009; 43(4):303–311. [PubMed: 19335571]
- Criley JM, Keiner J, Boker JR, Criley SR, Warde CM. Innovative Web-based multimedia curriculum improves cardiac examination competency of residents. *J Hosp Med.* 2008; 3(2):124–133. [PubMed: 18438809]

- Domagk S, Schwartz RN, Plass JL. Interactivity in multimedia learning: An integrated model. *Comput Hum Behav.* 2010; 26(5):1024–1033.
- Ekstrom, RB.; French, JW.; Harman, HH.; Dermen, D. Kit of factor-referenced cognitive tests. Princeton, NJ: Educational Testing Service; 1976.
- Engelkamp, J.; Zimmer, HD. The human memory: A multi-modal approach. Seattle, WA: Hogrefe & Huber; 1994.
- Garg A, Norman G, Sperotable L. How medical students learn spatial anatomy. *Lancet.* 2001; 357(9253):363–364. [PubMed: 11211004]
- Hattie, J. Visible learning: A synthesis of over 800 meta-analyses relating to achievement. London & New York: Routledge; 2009.
- Jang KS, Hwang SY, Park SJ, Kim YM, Kim MJ. Effects of a Web-based teaching method on undergraduate nursing students' learning of electrocardiography. *J Nurs Educ.* 2005; 44:35–39. [PubMed: 15673173]
- Keehner M, Hegarty M, Cohen C, Khooshabeh P, Montello DR. Spatial reasoning with external visualizations: what matters is what you see, not whether you interact. *Cognitive Sci.* 2008; 32(7): 1099–132.
- Kopp V, Stark R, Fischer MR. Fostering diagnostic knowledge through computer-supported, case-based worked examples: Effects of erroneous examples and feedback. *Med Educ.* 2008; 42(8): 823–829. [PubMed: 18564096]
- Leutner D, Kretschmar R. Visualization and activation: Surprising effects of two didactic principles/ Veranschaulichung und Aktivierung: Überraschende Effekte zweier didaktischer Prinzipien. *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie.* 1988; 20(3):263–276.
- McGaghie WC. Effect of practice on standardised learning outcomes in simulation-based medical education. *Med Educ.* 2006; 40(8):792–797. [PubMed: 16869926]
- Mayer R, Chandler P. When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages? *J Educ Psychol.* 2001; 93(2):390–397.
- Moreno R, Mayer R. Role of guidance, reflection, and interactivity in an agent-based multimedia game. *J Educ Psychol.* 2005; 97(1):117–128.
- Park SI, Lee G, Kim M. Do students benefit equally from interactive computer simulations regardless of prior knowledge levels? *Comput Educ.* 2009; 52(3):649–655.
- Plass J, Chun D, Mayer R, Leutner D. Cognitive load in reading a foreign language text with multimedia aids and the influence of verbal and spatial abilities. *Comput Hum Behav.* 2003; 19:221–243.
- Plass JL, Homer BD, Hayward E. Design factors for educationally effective animations and simulations. *J Comput Higher Educ.* 2009; 21(1):31–61.
- Plass, JL.; Moreno, R.; Brunken, R., editors. Cognitive Load Theory. New York: Cambridge; 2010.
- Pollock E, Chandler P, Sweller J. Assimilating complex information. *Learn Instr.* 2002; 12(1):61–86.
- Ramani S. Twelve tips for excellent physical examination teaching. *Med Teach.* 2008; 30:851–856. [PubMed: 18821164]
- Schneider PJ, Pederson CA, Montanya KR, Curran CR, Harpe SE, Bohenek W, Perratto B, Swaim J, Wellman KE. Improving the safety of medication using an interactive CD-ROM programme. *Am J Health-Syst Ph.* 2006; 63:59–64.
- Schnotz W, Bockheler J, Grzondziel H. Individual and co-operative learning with interactive animated pictures. *Eur J Psychol Educ.* 1999; 14(2):245–265.
- Schwamborn A, Thillmann H, Opfermann M, Leutner D. Cognitive load and instructionally supported learning with provided and learner-generated visualizations. *Comput Hum Behav.* 2011; 27(1):89–93.
- Schwartz, RN. Unpublished doctoral dissertation. New York University; 2010. Considering the activity in interactivity: A multimodal perspective.
- Stull AT, Mayer RE. Learning by doing versus learning by viewing: Three experimental comparisons of learner-generated versus author-provided graphic organizers. *J Educ Psychol.* 2007; 99(4):808–820.
- Wittrock MC. A generative model of mathematics learning. *J Res Math Educ.* 1974; 5(4):181–196.

Practice Points

- Well-designed Computer Assisted Instruction (CAI) has the potential to transform medical education but is currently not achieving its full potential
- Evidence-based guidance on the relative advantages of specific instructional and technical design features is needed to maximize learning in CAI
- A mid-range of physical interactivity was associated with small to moderate improvements in performance of clinical skills
- Interactivity may impose cognitive burdens as well as benefits, multimedia materials must be carefully designed to be neither too high nor too low in cognitive engagement

Figure 1.
Screenshot of the multimedia module on clinical performance of an abdominal exam:
"Practice Inspection," click version.

Table 1

Level of students' prior experience with examination of the abdomen; prior knowledge and spatial relations ability by type of content manipulation

Baseline	Watch (n=42)	Click (n=51)	Drag (n=50)
Prior Experience ¹			
	None	24(57.1%)	28(54.9%)
- In Educational setting ²	1-2	6(14.3%)	8(15.7%)
	>3	12(28.6%)	15(30.0%)
- In Professional setting	None	38(90.5%)	41(80.4%)
	1-2	2(4.8%)	4(8.0%)
	>3	2(4.8%)	6(11.8%)
- In IBD course	None	39(92.9%)	46(90.2%)
	1-2	1(2.4%)	3(5.9%)
	>3	2(4.7%)	5(10.0%)
Prior Knowledge (17) ³	6.05 (1.67)	5.73 (2.04)	5.70 (2.05)
Spatial Relations Ability (160) ³	101.74 (25.60)	111.89 (27.34)	100.40 (32.39)

Note:

¹Unit: Count(%)

²Except for IBD course

³Maximum possible score; Unit: Mean(SD)

Table 2

Mean scores and standard deviations for the types of content manipulation on the knowledge post-test and the physical examination

	Watch (n=42)	Click (n=51)	Drag (n=50)	Partial Eta Squared
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	
Knowledge Post-test (out of 18)	13.98 (1.66)	14.04 (2.11)	13.90 (1.91)	
Physical Exam (Overall, % ¹)	58 (20)	65 (16)	56 (19)	.046
Inspection	82 (27)	82 (31)	90 (23)	
Auscultation	55 (50) ²	80 (40) ²	77 (43)	.060
Palpation	49 (32)	60 (27) ³	45 (31) ³	.050
Percussion	43 (50)	49 (50)	46 (50)	
Additional Maneuver	45 (37)	60 (37) ⁴	40 (38) ⁴	.053

Note:

¹ % of well done on SP abdominal examination

² Tukey's post-hoc test (difference=.50, 95% CI: .03 ~ .48), Cohen's d = .55

³ Tukey's post-hoc test (difference=.15, 95% CI: .01 ~ .30), Cohen's d = .26

⁴ Tukey's post-hoc test (difference=.20, 95% CI: .02 ~ .38), Cohen's d = .53

Table 3

Time-on-task for steps of the abdominal exam by each type of content manipulation

Stage	Watch (<i>n</i> =42)	Click (<i>n</i> =50)	Drag (<i>n</i> =49)
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
Inspection	181.49 (36.35)	329.13 (79.25)	206.76 (66.15)
Auscultation	118.08 (41.14)	139.25 (56.67)	156.28 (80.14)
Palpation	253.84 (83.50)	278.22 (98.99)	309.12 (119.21)
Percussion	246.13 (64.50)	256.73 (74.19)	262.07 (76.42)
Add'l maneuver	125.34 (37.34)	134.06 (40.90)	123.36 (28.90)
Total	971.5 (233.59)	1181.29 (247.96)	1106.70 (272.59)

Note:

1. Time-on-Task (seconds)
2. Data from Introduction section was excluded because it was very short and identical for all students