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ORIGINAL ARTICLE

Lack of interaction between sensing–intuitive learning styles and problem-first versus information-first instruction: a randomized crossover trial

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Abstract
Background Adaptation to learning styles has been proposed to enhance learning. *Objective* We hypothesized that learners with sensing learning style would perform better using a problem-first instructional method while intuitive learners would do better using an information-first method. *Design* Randomized, controlled, crossover trial. *Setting* Resident ambulatory clinics. *Participants* 123 internal medicine residents. *Interventions* Four Web-based modules in ambulatory internal medicine were developed in both "didactic" (information first, followed by patient problem and questions) and "problem" (case and questions first, followed by information) format. *Measurements* Knowledge posttest, format preference, learning style (Index of Learning Styles). *Results* Knowledge scores were similar between the didactic (mean ± standard error, 83.0 ± 0.8) and problem (82.3 ± 0.8) formats (p = .42; 95% confidence interval [CI] for difference, −2.3 to 0.9). There was no difference between formats in regression slopes of knowledge scores on sensing-intuitive scores (p = .63) or in analysis of knowledge scores by styles classification (sensing 82.5 ± 1.0, intermediate 83.7 ± 1.2, intuitive 81.0 ± 1.5; p = .37 for main effect, p = .59 for interaction with format). Format preference was neutral (3.2 ± 0.2 [1 strongly prefers didactic, 6 strongly prefers problem], p = .12), and there was no association between learning styles and preference (p = .44). Formats were similar in time to complete modules (43.7 ± 2.2 vs 43.2 ± 2.2 minutes, p = .72). *Conclusions* Starting instruction with a problem (versus employing problems later on) may

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not improve learning outcomes. Sensing and intuitive learners perform similarly following problem-first and didactic-first instruction. Results may apply to other instructional media.

Keywords Cognitive style · Internet · Instructional method · Learning style · Medical education · Problem-based learning · Web-based learning

Introduction

Adaptation to individual differences such as learning styles has been proposed to enhance Web-based learning (WBL) (Cook 2005c), but evidence to support such propositions is scant (Cook 2005a). The strongest evidence in support of adaptation would demonstrate an aptitude–treatment interaction, in which learners with one attribute (e.g. learning style) do better with a given instructional intervention (e.g. instructional method) while learners with another attribute do better with an alternate intervention. However, a recent review of research investigating computer-assisted instruction (CAI) and learning styles found that most studies were designed to look for associations rather than causal relationships and interactions (Cook 2005a). Thus, research designed to investigate aptitude–treatment interactions (Cronbach and Snow 1977) is needed to clarify the role of adaptation in WBL. This article reports one such study.

Knowledge becomes useful when a learner applies (transfers) it to a new setting. Effective transfer is difficult because knowledge is situated, or context-bound—a “product of the activity, context, and culture in which it is developed and used.”(Brown et al. 1989). Theory and evidence suggest that using clinical problems during instruction improves learning and facilitates transfer (Bransford et al. 2000; Cook et al. 2006; Norman 2005).

A widely prevalent view considers problem-first instruction (initiating instruction with a case/question) to be superior to introducing problems later in the course. However, there is some evidence that starting with a problem can have deleterious effects such as impeding transfer (if learning is linked to irrelevant features of the problem context (Ross 1987)) or reinforcing a method of reasoning inconsistent with the reasoning patterns of experts (Patel et al. 1991) We are not aware of research directly investigating the impact of problem sequence in WBL.

Felder and Silverman described a sensing–intuitive learning style dimension (Felder and Silverman 1988), which is similar both theoretically (Cook 2005a) and empirically (Cook and Smith 2006) to Kolb’s concrete–abstract dimension (Kolb 1984). Sensing learners prefer “what is real”—facts, data, and experimentation—while intuitive learners look for patterns and meaning—principles and theories. Thus, sensors might learn better using a case-based approach (opportunity for vicarious experimentation) while intuitors might learn better using a didactic approach (focus on theories and ideas) (Felder 1993). One study in business education (Bostrum et al. 1990) confirmed a predicted interaction between concrete–abstract learning styles and case-based versus non-case-based instructional methods. However, another study from computer science education (Melara 1996) found no difference between sensing and intuitive learners when instruction was organized in a hierarchical versus network structure. Other studies have failed to show influence from sensing–intuitive styles (Cook et al. 2006, 2007; Fleming et al. 2003; Hart 1995; Lowdermilk and Hopkins Fishel 1991; Lynch et al. 2001; Reed et al. 2000; Rourke and Lysynchuk 2000). However, the interventions in these latter studies were not designed to highlight sensing–intuitive differences. It appears that this style dimension merits further investigation.

We hypothesized that (1) internal medicine residents with sensing learning style using a problem-first approach will have higher knowledge test scores and improved learning efficiency (knowledge scores per time spent) than sensing learners using an information-first approach, while the opposite will be true for intuitive learners, and (2) sensing learners will prefer the problem-first approach while intuitive learners will prefer information-first. We further anticipated that, should these hypotheses not find support, learning outcomes (knowledge scores and format preference) would favor the problem-first approach.

Methods

Setting and sample

To evaluate these hypotheses we conducted a randomized crossover trial in which each participant used both a problem-first format and an information-first format. All 143 categorical residents in the Mayo-Rochester Internal Medicine Residency Program were invited to participate. This study took place in their weekly continuity clinic during the 2004–2005 academic year. Our Institutional Review Board approved this study. All participants gave consent.

Interventions and randomization

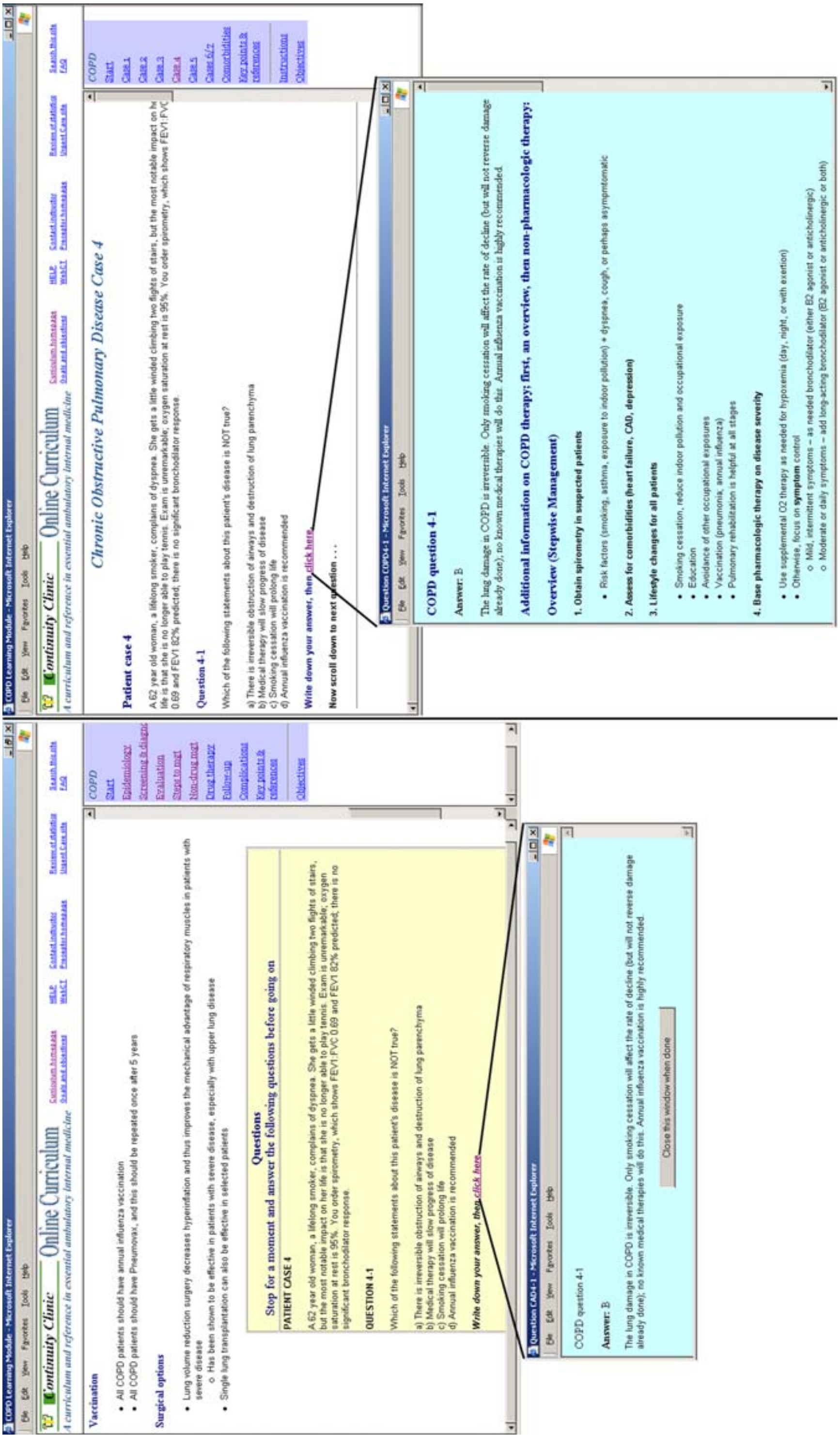
We developed evidence-based WBL modules (Cook et al. 2005) on four ambulatory medicine topics: hypertension, coronary artery disease, chronic obstructive pulmonary disease, and obesity. Each module consisted of didactic information (text, tables, illustrations, and hyperlinks to online resources) and 12–15 case-based problems (patient scenarios followed by multiple-choice questions with answers that included a brief explanation). Each module was developed in both information-first ("*didactic*") and problem-first ("*problem*") format. In the didactic format a short block of information was followed by one or more problems, which residents answered before proceeding to the next block. In the problem format, problems were presented first and relevant didactic information was provided immediately after the answer/explanation. Over the course of all problems, all of the didactic information was presented. Thus, both the didactic content and the problems/explanations were identical between the two formats, and only the presentation sequence varied (Fig. 1).

Participants completed two modules using the didactic format and two modules using the problem format. Sequence was determined randomly using MINIM (version 1.5, London Hospital Medical College, London), with stratification by postgraduate year and clinic site.

Instruments and outcomes

One primary outcome, knowledge, was determined using a test at the end of each module.[1] Seventy-nine case-based multiple-choice questions designed to assess application of knowledge (Case and Swanson 2001) and address each module's objectives were reviewed

[1] We intentionally avoided the use of a pretest because of the weaknesses the pretest introduces to education research (Fraenkel and Wallen 2003). In a randomized study, individual differences (including knowledge assessed on pretest) should be distributed equally among groups, obviating the need for a pretest.


COPD Learning Module - Microsoft Internet Explorer
Continuity Clinic
Online Curriculum
A curriculum and reference in essential ambulatory internal medicine
Chronic Obstructive Pulmonary Disease Case 4
Patient case 4
Question 4-1
Which of the following statements about this patient's disease is NOT true?
a) There is irreversible obstruction of airways and destruction of lung parenchyma
b) Medical therapy will slow progress of disease
c) Smoking cessation will prolong life
d) Annual influenza vaccination is recommended
Write down your answer, then click here.
Now scroll down to next question . . .
COPD question 4-1
Answer: B
The lung damage in COPD is irreversible. Only smoking cessation will affect the rate of decline (but will not reverse damage already done); no known medical therapies will do this. Annual influenza vaccination is highly recommended.
Additional information on COPD therapy: first, an overview, then non-pharmacologic therapy:
Overview (Stepwise Management)
1. Obtain spirometry in suspected patients
2. Assess for comorbidities (heart failure, CAD, depression)
3. Lifestyle changes for all patients
4. Base pharmacologic therapy on disease severity
Vaccination
Surgical options
Questions
Stop for a moment and answer the following questions before going on
PATIENT CASE 4
QUESTION 4-1
Close this window when done

◀**Fig. 1** Appearance and features of a representative Web-based module. Screen shots of a representative module. The image on the left is from a didactic format module, while the image on the right illustrates the problem format. Content, cases, questions, and answers/rationale were identical between the two formats; only the sequence of presentation changed

by experts and pilot-tested on internal medicine faculty as per previous modules (Cook et al. 2005). At the end of the academic year residents completed a cumulative test ("delayed test") comprising all questions from each posttest. Residents received answers only following the delayed test. Delayed tests completed within 3 weeks of the most recent posttest were excluded from analysis. Prior to each posttest residents recorded the time spent on that module.

The other primary outcome, format preference, was assessed on an end-of-course questionnaire along with comparisons of perceived efficiency and effectiveness.

Learning style was assessed using the Index of Learning Styles (Felder and Soloman 2007) (ILS), which provides scores for four style dimensions (active–reflective, visual–verbal, sensing–intuitive, and sequential–global). Scores range −11 to +11 in increments of two (−11, −9, ... 7, 9, 11). Scores between −3 and +3 were classified as "intermediate." Evidence supports the validity of ILS scores for determining the sensing–intuitive learning styles of internal medicine residents (Cook 2005b; Cook and Smith 2006).

All tests and questionnaires were administered using WebCT (version 3.8, WebCT, Inc., Lynnfield, Massachusetts).

Statistical analysis

Test scores were compared over time and between the two formats using mixed linear models[2] accounting for repeated measurements on each subject and for differences among modules. For the comparison between formats, additional adjustments were planned for group assignment, postgraduate year, gender, and clinic site. Mixed models were also used to investigate potential associations between format preference and test scores, and test scores and learning styles. The mixed models analysis was repeated for the delayed test, with additional adjustment for time from last posttest to delayed test.

Format preference was analyzed using the Wilcoxon signed rank test, testing the null hypothesis that there was no preference. The Wilcoxon rank sum test or Kruskal–Wallis test was used for comparisons among two or more groups. General linear models were used to determine associations between preference ratings and sensing–intuitive scores, and also to evaluate the possibility of simultaneous effects from multiple learning styles on preference. The fit of this parametric model was assessed and deemed adequate for analysis of this ordinal variable. Similar analyses were performed for perceived effectiveness and efficiency.

Time required to complete modules and learning efficiency (knowledge test score divided by time spent) were analyzed using mixed linear models. Regression model assumptions were not met for learning efficiency, and thus only analysis of variance results are reported.

All analyses were performed using intention-to-treat and a two-sided alpha level of 0.05. The expected sample size of 86 participants was to provide 90% power to detect a

[2] In the mixed linear model, analysis of variance (ANOVA) is a special case of linear regression. Thus the mixed linear model can be used for both regression and analysis of variance.

difference of 0.5 points in preference and a 7% change in knowledge test score. All analyses were performed using SAS 9.1 (SAS Institute Inc., Cary, North Carolina).

Results

One hundred and twenty-three residents consented to participate and were randomized (see Fig. 2). One hundred and seven residents (87%) completed at least one module, 102 (83%) completed all modules, and 91 (74%) completed the final survey. Demographics are summarized in Table 1. Eighty-eight residents (72%) completed the ILS and at least three modules; among these, 39 (45%) were sensing, 30 (34%) were intermediate, and 18 (21%) were intuitive. Among those completing the delayed test, 30 (47%) were sensing, 23 (36%) were intermediate, and 11 (17%) were intuitive.

Cronbach's alpha for knowledge test scores was 0.72. Individual and simultaneous adjustment for postgraduate year, gender, comfort using the Internet, and prior WBL experience had no significant effect on any reported analyses except as noted.

Effect of sensing–intuitive styles

There was no significant interaction between instructional format and sensing–intuitive learning style scores ($b_{didactic} = -0.070$ knowledge points [%] per 1-unit increase in ILS score, $b_{problem} = 0.003$; $p = .63$ for difference in slopes) on knowledge scores. To facilitate interpretation of these results, sensing–intuitive scores were classified into sensing, intermediate, or intuitive styles, and knowledge scores for these styles are reported in Table 2. Similar results were found when analyzing delayed knowledge test scores ($b_{didactic} = -0.17$, $b_{problem} = -0.38$; $p = .23$ for difference in slopes).

Learner format preference (see Fig. 3) was assessed using a scale ranging from 1 (strongly prefer didactic) to 6 (strongly prefer problem). There was no association between

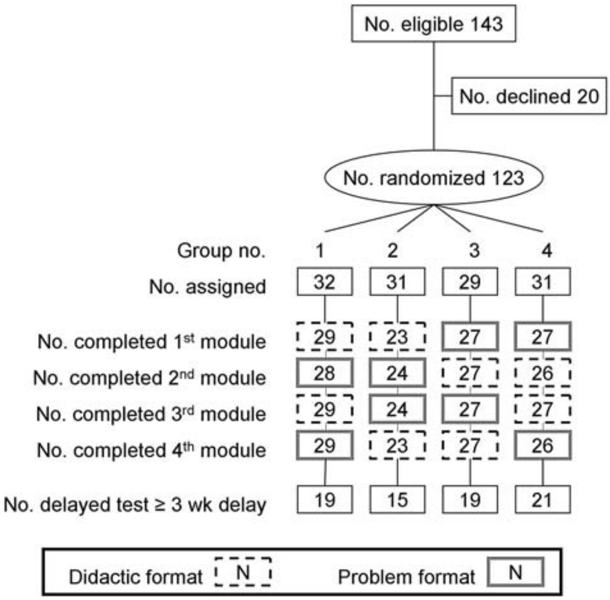


Fig. 2 Participant flow chart. Study enrollment and number of participants completing each module knowledge test. All data available at each time point were included in analysis

Table 1 Characteristics of study participants

Group or response[a]	Number of participants[a]			
	Group 1 ($n = 32$) No. (%)	Group 2 ($n = 31$) No. (%)	Group 3 ($n = 29$) No. (%)	Group 4 ($n = 31$) No. (%)
Gender				
Female	15 (47)	14 (45)	8 (28)	7 (22)
Postgraduate year				
1	11 (34)	11 (35)	10 (34)	12 (39)
2	11 (34)	11 (35)	10 (34)	10 (32)
3	10 (32)	9 (29)	9 (31)	9 (29)
Post-residency plans				
General internal medicine	6 (22)	2 (8)	2 (8)	3 (12)
Internal medicine subspecialty	19 (70)	22 (85)	21 (88)	20 (77)
Non-IM specialty	1 (4)	1 (4)	1 (4)	1 (4)
Undecided	1 (4)	1 (4)	0	2 (8)
Prior experience with Web-based learning				
None	6 (21)	5 (20)	3 (12)	4 (16)
1–2 courses	6 (21)	7 (28)	6 (23)	6 (24)
3–5 courses	7 (25)	5 (20)	5 (19)	6 (24)
6 or more courses	9 (32)	8 (32)	12 (46)	9 (36)
Comfort using the Internet				
Uncomfortable	8 (29)	3 (12)	4 (15)	4 (16)
Neutral	3 (11)	0	1 (4)	0
Comfortable	17 (61)	22 (88)	21 (81)	21 (84)
Sensing–intuitive learning style				
Sensing	11 (41)	7 (29)	13 (50)	11 (48)
Intermediate	11 (41)	9 (38)	6 (23)	7 (30)
Intuitive	5 (18)	8 (33)	7 (27)	5 (22)

A total of 123 residents participated. Each completed two modules using an information-first format and two modules using a problem-first format in a crossover fashion, with sequence randomized

[a] Number of responses varies because information was obtained from different questionnaires and not all respondents answered all questions. All percentages are calculated for group totals i.e. for the column

format preference and sensing–intuitive learning style scores in regression analysis ($b = 0.03$, $p = .44$; see also Table 2).

There was no difference in learning efficiency (knowledge score divided by time spent on module) between learners with sensing, intermediate, and intuitive styles ($p = .26$; see Table 2). Likewise, there was no interaction ($p = .95$) between format and sensing–intuitive style classifications when looking at learning efficiency.

Effect of instructional format

After adjusting for differences among modules there was no difference in knowledge scores between the didactic (mean ± standard error of the mean, 83.0 ± 0.8) and problem

Table 2 Knowledge test scores and format preference, efficiency, and effectiveness by sensing–intuitive learning style classification

Outcome	Learning style			p^a
	Sensing Mean ± SEM (CI)	Intermediate Mean ± SEM (CI)	Intuitive Mean ± SEM (CI)	
Immediate knowledge test (% correct)	82.5 ± 1.0 (80.4–84.6)	83.7 ± 1.2 (81.4–86.0)	81.0 ± 1.5 (78.0–84.0)	.37
Delayed knowledge test (% correct)	76.8 ± 1.6 (73.6–80.0)	76.0 ± 1.8 (72.4–79.6)	74.0 ± 2.6 (68.9–79.1)	.65
Learning efficiency (% correct/minute [immediate knowledge test])	2.6 ± 0.2 (2.2–3.0)	2.4 ± 0.2 (2.0–2.8)	3.0 ± 0.3 (2.4–3.5)	.26
Preference[b]	3.0 ± 0.3 (2.4–3.6)	3.5 ± 0.4 (2.8–4.2)	3.4 ± 0.5 (2.5–4.4)	.43
Efficiency[b]	3.0 ± 0.3 (2.4–3.5)	3.4 ± 0.3 (2.7–4.0)	3.5 ± 0.5 (2.5–4.5)	.55
Effectiveness[b]	3.0 ± 0.3 (2.4–3.5)	3.6 ± 0.3 (3.0–4.2)	3.6 ± 0.4 (2.6–4.5)	.28

[a] p value for simultaneous comparison between all three styles using analysis of variance or Kruskal–Wallis; p values for pairwise comparisons not reported because all $p > .05$

[b] Preference, Efficiency, and Effectiveness were measured using a 6-point scale, where 1 = strongly favor didactic and 6 = strongly favor problem

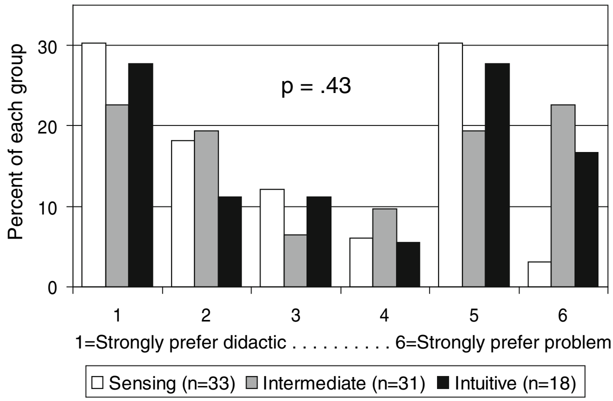


Fig. 3 Format preference. Using a scale ranging from 1 = strongly prefer didactic-first to 6 = strongly prefer problem-first, there was no difference in format preference between learners according to sensing–intuitive learning style classifications ($p = .43$)

(82.3 ± 0.8) formats ($p = .42$; CI for difference, −2.3 to 0.9). Those with no prior WBL experience had lower knowledge scores (78.0 ± 1.6) than those with prior WBL experience (84.0 ± 1.3 for those having taken one or two courses, 83.2 ± 0.9 for three or more; $p = .01$ compared to no experience); the difference between instructional formats remained nonsignificant ($p = .69$) after adjusting for this variable.

Knowledge scores among those preferring the problem format (82.4 ± 1.1) and those preferring didactic (83.1 ± 1.0) were not significantly different ($p = .60$; CI for difference −3.5 to 2.0). However, there was a statistically significant interaction between preference (treated as a continuous variable) and format ($b_{\text{problem}} = 0.11$ knowledge points per 1-unit increase in preference [6-point scale], $b_{\text{didactic}} = -0.85$, $p = .037$ for difference in slopes). Again using means to facilitate interpretation, those preferring the didactic format did slightly better with didactic (83.6 ± 1.1) than with problem (82.6 ± 1.1) modules, while those preferring the problem format did better with problem (83.0 ± 1.3) than with didactic (81.8 ± 1.3) modules.

Scores on the delayed knowledge test were not significantly different between the didactic (77.0 ± 1.2) and problem (75.4 ± 1.2) formats both before ($p = .06$) and after ($p = .11$) adjustment for time from immediate test to delayed test (CI for difference −3.5 to 0.4). There was no difference in delayed knowledge test scores between residents preferring the didactic format (76.0 ± 1.4) and those preferring problem (75.9 ± 1.9, $p = .97$; CI for difference −4.7 to 4.6). The interaction between format and preference was no longer present on the delayed knowledge test ($p = .61$).

As shown in Fig. 3, there was wide variation in learner format preference with a mean of 3.2 ± 0.2 (CI: 2.8–3.6), which is not different ($p = .12$) than the neutral preference of 3.5.

Effectiveness and learning efficiency

On a scale ranging from 1 (didactic much more efficient/effective) to 6 (problem much more efficient/effective), there was no difference in perceived effectiveness (3.3 ± 0.2, $p = .20$) or efficiency (3.2 ± 0.2, $p = .10$) between the instructional formats.

Knowledge scores were similar between those rating didactic as more effective (82.9 ± 1.0) and those rating problem as more effective (82.6 ± 1.1, $p = .84$). However, interaction was present between perceived effectiveness and format ($b_{\text{problem}} = 0.25$, $b_{\text{didactic}} = -0.77$, $p = .048$): those feeling that didactic was more effective scored slightly higher on didactic (83.6 ± 1.1) than on problem modules (82.2 ± 1.1), while those favoring problem scored higher on problem modules (83.5 ± 1.2) than on didactic (81.8 ± 1.3). In contrast, perceived efficiency had no main effect ($p = .81$) on knowledge scores or interaction with format ($p = .36$).

There was no difference in self-reported time to complete the modules between the didactic (43.7 ± 2.2 min) and the problem (43.2 ± 2.2, $p = .72$; CI for difference −2.0 to 2.9) formats. Likewise, learning efficiency was similar between formats (2.5 ± 0.1 points/min for didactic, 2.6 ± 0.1 for problem, $p = .80$; CI for difference −0.2 to 0.1). There was no interaction between format and *perceived* learning efficiency when looking at *measured* learning efficiency ($p = .81$): those feeling that didactic was more efficient had similar measured efficiency regardless of format (both formats 2.5 ± 0.2 points/min), and the same was true for those who rated problem as more efficient (both formats 2.6 ± 0.2).

Associations with other learning styles

In exploratory analyses active–reflective, visual–verbal, and sequential–global learning styles did not interact with instructional method to influence knowledge scores, nor was there a main effect from these characteristics ($p > .08$). Likewise, these styles had no association with format preference ($p > .26$).

Discussion

This study hypothesized that sensing–intuitive learning styles would interact with problem-first versus information-first instruction to influence knowledge test scores among internal medicine residents. No evidence was found to support this interaction, nor was there an association between sensing–intuitive styles and knowledge test scores or format preference. Likewise, the timing of problems had no effect on learning outcomes.

It is necessary to frame this study in the context of previous learning styles research. Considering first the sensing–intuitive dimension, a review of literature on learning styles in CAI (Cook 2005a) found one study showing interaction between sensing–intuitive styles and instructional design, and one study showing differences between sensing and intuitive learners (the latter study did not assess interaction). Although several uncontrolled and controlled experiments had found no influence of sensing–intuitive styles on CAI and WBL, the review concluded that methodological flaws and a paucity of theory-driven research might account for the lack of evidence supporting aptitude–treatment interactions. The present study represents only one experiment, and other interventions might have led to different results. However, when combined with two recent controlled studies (Cook et al. 2006, 2007) indicating no influence from sensing–intuitive styles, it appears from the preponderance of evidence that sensing–intuitive styles have little impact, if any, on educational outcomes in WBL.

Turning attention to learning styles in general, educators have long been intrigued by the possibility of using learning styles to better meet the needs of individual learners. Unfortunately, while decades of research has found interesting associations between learning styles and various outcomes (Curry 2000), the practical utility of such research is limited. As noted above, a recent review (Cook 2005a) tentatively concluded that some learning styles (specifically, concrete–abstract [sensing–intuitive] and active–reflective styles) might influence WBL. However, in light of the negative findings in the present study and other recent research (Cook et al. 2006, 2007), it seems that learning styles may be less useful than anticipated. We agree with others (Clark 2005; Merrill 2002) that, rather than trying to use learning styles to adapt instruction to individual learners, educators' effort will be better spent ensuring that the most effective instructional methods are used for a given learning objective.

It has become common practice to begin instruction with a case and questions, yet our results suggest that the order in which problems appear in a course may not be very important. These findings are not conclusive because it is possible that in the didactic-first format the first problem might have activated prior knowledge to improve learning while studying the second block of didactic information, the second problem might have facilitated learning in the third block, and so on (an effect found in previous research (Boshuizen et al. 1998)). Nonetheless we tentatively conclude that the *presence* of problems is more important than the actual *order* in which these appear in a course, and call for research to confirm and clarify this proposition. In addition to investigating the effectiveness of interspersing problems and didactics versus beginning or ending with a series of problems, it may also be useful to examine the timing of answers/explanations relative to didactics in the problem-first format.

Residents had slightly higher knowledge scores when using the module format that they preferred and felt was most effective, suggesting that learners' perceptions of preference and effectiveness had some degree of accuracy. Given the absent effect of learning styles, these findings further suggest that learner selection of instructional methods based on personal preference is better than teacher (or computer) selection based on learning styles.

It is possible that the failure to find main effects from or interaction between instructional formats and learning styles was due to flawed operationalization of learning style differences or to instructional methods that were too alike, and thus other variations in instructional design could have different results. The inclusion of learners of intermediate style (Cronbach and Snow 1977) is a further limitation. We also cannot exclude the possibility that learners already knew the content of this course, although our previous experience found an 11% improvement in test scores using similar modules albeit for different clinical topics (Cook et al. 2005). No group received didactics without problems because that format was shown to be inferior in a previous study (Cook et al. 2006). The delayed test results are limited by loss to follow-up and by the possibility that learners might have studied or discussed these topics prior to the test, although the decline in delayed test scores makes the latter concern less likely. The study involved a single training program that may not be representative of other programs. Finally, the learners in this study were residents, and these results may not apply to learners with different clinical experience, domain-specific prior knowledge (e.g. preclinical medical students), or learning proficiency.

Future research should continue to study instructional theories, methods, and designs in WBL. We believe the results of many such studies will not be limited to CAI, but will inform theories and practices in various instructional contexts and media. While it seems increasingly unlikely that learning styles influence learning, confirmation of our findings in other contexts and among other learners is necessary. Educators should avoid using learning styles to inform decisions or instructional adaptations until evidence supporting such use is available. Studies are also needed to confirm our findings regarding the role and sequence of the patient problem, and to further explore the use of problems, questions, and other instructional methods to activate knowledge and reinforce learning. Finally, research should investigate the role of teacher- or computer-guided versus learner-initiated adaptations in WBL.

In conclusion, it seems that sensing–intuitive learning styles have no consistent effect on learning outcomes in WBL. Starting an instructional session with a patient case may not significantly improve learning outcomes compared to introducing the case later in the sequence of instructional events. Additional research to clarify WBL instructional designs and theories is needed.

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References

Boshuizen, H. P. A., Machiels-Bongaerts, M., van de Wiel, M. W. J., & Schmidt, H. G. (1998). *Learning from multiple cases: A new paradigm for investigating the effects of clinical experience on knowledge restructuring and knowledge acquisition*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, April 1998.

Bostrum, R. P., Olfman, L., & Sein, M. K. (1990). The importance of learning style in end-user training. *MIS Quarterly, 14*, 101–119.

Bransford, J. D., Brown, A. L., Cocking, R. R., & for the Committee on Developments in the Science of Learning and the Commission on Behavioral and Social Sciences and Education of the National Research Council (Eds.). (2000). *How people learn: brain, mind, experience, and school*. Washington, DC: National Academy Press.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated learning and the culture of learning. *Education Researcher, 18*, 32–42.

Case, S. M., & Swanson, D. B. (2001). *Constructing written test questions for the basic and clinical sciences* (3rd ed.). Philadelphia, PA: National Board of Medical Examiners.

Clark, R. E. (2005). Five common but questionable principles of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 97–115). New York: Cambridge University Press.

Cook, D. A. (2005a). Learning and cognitive styles in Web-based learning: Theory, evidence, and application. *Academic Medicine, 80*, 266–278.

Cook, D. A. (2005b). Reliability and validity of scores from the Index of Learning Styles. *Academic Medicine, 80*(10 suppl), S97–S101.

Cook, D. A. (2005c). The research we still are not doing: An agenda for the study of computer-based learning. *Academic Medicine, 80*, 541–548.

Cook, D. A., Dupras, D. M., Thompson, W. G., & Pankratz, V. S. (2005). Web-based learning in residents' continuity clinics: A randomized, controlled trial. *Academic Medicine, 80*, 90–97.

Cook, D. A., Gelula, M. H., Dupras, D. M., & Schwartz, A. (2007). Instructional methods and cognitive and learning styles in web-based learning: Report of two randomised trials. *Medical Education, 41*, 897–905.

Cook, D. A., & Smith, A. J. (2006). Validity of Index of Learning Styles scores: Multitrait–multimethod comparison with three cognitive/learning style instruments. *Medical Education, 40*, 900–907.

Cook, D. A., Thompson, W. G., Thomas, K. G., Thomas, M. R., & Pankratz, V. S. (2006). Impact of self-assessment questions and learning styles in web-based learning: A randomized, controlled, crossover trial. *Academic Medicine, 81*, 231–238.

Cronbach, L. J., & Snow, R. E. (1977). *Aptitudes and instructional methods: A handbook for research on interactions*. New York: Irvington Publishers.

Curry, L. (2000). Review of learning style, studying approach, and instructional preference research in medical education. In R. J. Riding & S. G. Rayner (Eds.), *International perspectives on individual differences, volume 1: Cognitive styles* (pp. 239–276). Stamford, CT: Ablex Publishing Corporation.

Felder, R. M. (1993). Reaching the second tier: Learning and teaching styles in college science education. *Journal of College Science Teaching, 23*, 286–290.

Felder, R. M., & Silverman, L. K. (1988). Learning and teaching styles in engineering education. *Journal of Engineering Education, 78*(7), 674–681.

Felder, R. M., & Soloman, B. A. (2007). *Index of learning styles*. Retrieved July 17, 2007, from http://www.ncsu.edu/felder-public/ILSpage.html.

Fleming, D. E., Mauriello, S. M., McKaig, R. G., & Ludlow, J. B. (2003). A comparison of slide/audiotape and web-based instructional formats for teaching normal intraoral radiographic anatomy. *Journal of Dental Hygiene, 77*, 27–35.

Fraenkel, J. R., & Wallen, N. E. (2003). *How to design and evaluate research in education*. New York, NY: McGraw-Hill.

Hart, G. (1995). *Learning styles and hypertext: Exploring user attitudes.* Australian Society for Computers in Learning in Tertiary Education, Melbourne.

Kolb, D. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.

Lowdermilk, D. L., & Hopkins Fishel, A. (1991). Computer simulations as a measure of nursing students' decision-making skills. *Journal of Nursing Education, 30*, 34–39.

Lynch, T. G., Steele, D. J., Johnson Palensky, J. E., Lacy, N. L., & Duffy, S. W. (2001). Learning preferences, computer attitudes, and test performance with computer-aided instruction. *American Journal of Surgery, 181*, 368–371.

Melara, G. E. (1996). Investigating learning styles on different hypertext environments: Hierarchical-like and network-like structures. *Journal of Educational Computing Research, 14*, 313–328.

Merrill, M. D. (2002). Instructional strategies and learning styles: Which takes precedence? In R. Reiser & J. V. Dempsey (Eds.), *Trends and issues in instructional design and technology* (pp. 99–106). Upper Saddle River, NJ: Merrill/Prentice Hall.

Norman, G. (2005). Research in clinical reasoning: Past history and current trends. *Medical Education, 39*, 418–427.

Patel, V. L., Groen, G. J., & Norman, G. R. (1991). Effects of conventional and problem-based medical curricula on problem solving. *Academic Medicine, 66*, 380–389.

Reed, W. M., Oughton, J. M., Ayersman, D. J., Ervin, J. R., Jr., & Giessler, S. F. (2000). Computer experience, learning style, and hypermedia navigation. *Computers in Human Behavior, 16*, 609–628.

Ross, B. H. (1987). This is like that: The use of earlier problems and the separation of similarity effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 629–639.

Rourke, L., & Lysynchuk, L. (2000). *The influence of learning style on achievement in hypertext.* Annual Meeting of the American Education Research Association, New Orleans, LA, April 24–28, 2000.