The Effects of Split-Attention and Redundancy on Cognitive Load When Learning Cognitive and Psychomotor Tasks

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Human working memory can be defined as a component system responsible for the temporary storage and manipulation of information related to higher level cognitive behaviors, such as understanding and reasoning (Baddeley, 1992; Becker & Morris, 1999). Working memory, while able to manage a complex array of cognitive activities, presents with an unexpected peculiarity, in that only a few elements of information can be processed in working memory at a given time. Miller (1956) established that working memory can only maintain about seven elements of information at a time. Additionally, working memory under conditions where rehearsal is limited, may only be able to hold information active for a few seconds (Peterson & Peterson, 1959). In situations involving more complex cognitive tasks, demands placed on working memory that are not directly related to problem solving can hinder learning by exceeding available cognitive resources (Sweller, van Merrienboer, & Paas, 1998). In such situations, instructional principles that avoid overburdening working memory and/or direct the learner's available resources are needed to design efficient and effective instruction.

Cognitive load theory, as conceptualized by Sweller (1988) and his colleagues in the late eighties, is concerned with instructional design and message design methods that efficiently manage the limited processing capabilities of an individuals working memory while capitalizing on the extensive capabilities of long term memory in order to promote schema formation and improve intellectual learning and performance of complex cognitive tasks.

Cognitive load (CL) is defined as the "total amount of mental energy imposed on working memory at an instance in time" (Cooper, 1998, p. 10). This "total" cognitive load is further subdivided into three subcomponents: intrinsic cognitive load (ICL), extraneous cognitive load (ECL) and germane cognitive load (GCL) (Sweller et al., 1998).

Intrinsic cognitive load is the load imposed on the learner by the nature of the instructional material that must be processed and learned. There is evidence to support the indirect manipulation of ICL by incorporating sequencing and layering strategies into the instructional design process and learning task (Pollock, Chandler, & Sweller, 2002).

Extraneous cognitive load is the load imposed by factors such as instructional strategies, message design, interface design, and the quality of instructional materials and learning environments. ECL is readily influenced by instructional design processes and has been the focus of much investigation (Sweller et al., 1998). In simple terms, high ECL equates to a reduction in working memory resources available for learning, while low ECL equates to an increase in working memory resources available for learning. Research related to the physical integration of diagrams and text and the elimination of unnecessary information in order to reduce demands on working memory has been conducted with much success in the knowledge domains of biology, computer-aided design/computer-aided manufacturing, electrical engineering, computer programming and mathematics (Bobis, Sweller, & Cooper, 1993; Chandler & Sweller, 1991, 1996; Kalyuga, Chandler, & Sweller, 1998; Leung, Low, & Sweller, 1997; Sweller et al., 1998; Tarmizi & Sweller, 1988).

A third and final dimension of cognitive load is germane cognitive load and is described as the "load imposed by cognitive processes directly relevant to learning" (van Merrienboer, Schuurman, de Croock, & Paas, 2002, p.12). The instructional designer can indirectly manipulate GCL. However, given that intrinsic + germane + extraneous cognitive load equals total cognitive load, the combination of ECL and ICL must leave sufficient resources available if GCL is to be addressed (Kirschner, 2002; van Merrienboer et al., 2002).

Currently, the study of cognitive load theory has provided hypotheses and conclusive findings concerning appropriate strategies for structuring instructional material as studied in many technical knowledge domains. The focus of this paper is to investigate the applicability of the cognitive load theory principles of redundancy and split attention to teaching Manual Physical Therapy Skills.

Literature Review

Working memory is loosely described as interconnected cognitive mechanisms that maintain newly acquired information and retrieve stored information to an active state for processing and manipulation. It is in working memory where complex cognitive tasks such as reasoning and problem solving occur (Baddeley, 1992; Becker & Morris, 1999). It is also in working memory where a potential bottleneck exists between the learning task at hand and long-term memory. Working memory while capable of managing an impressive array of cognitive tasks is surprisingly limited in both capacity and duration (Baddeley, 1992; Miller, 1956; Shiffrin & Nosofsky, 1994). In contrast, long-term memory effectively stores all of our knowledge (content, skills and strategies) on a permanent basis, with the ability to recall this information being somewhat more variable (Baddeley, 1992; Ericsson & Kintsch, 1995).

Element Complexity and Element Interactivity

In situations with low-element interactivity, such as with serial processing tasks, little or no overlap exists between elements but as the number of independent elements increases, the tasks may become difficult. In contrast, in situations with high-element interactivity where understanding requires that all elements be maintained in working memory and manipulated simultaneously, learning tasks can become exceptionally difficult. In such instances, the cognitive load imposed by trying to keep all elements in working memory may exceed the processing abilities of working memory (Sweller & Chandler, 1994).

Split Attention and Redundancy

Split attention and redundancy are closely linked concepts and in many cases are managed with similar design principles. For example, if two or more sources of information cannot be understood in isolation, then a split attention effect may occur and if they can be understood in isolation, a redundancy effect may occur (Kalyuga et al., 1998; Kalyuga, Chandler, & Sweller, 1999; Sweller, 1990, 1994, 1999; Sweller & Chandler, 1994; Sweller et al., 1998). Split attention and redundancy effects have been studied and can be practically categorized as (a) single format media studies, (b) dual format media studies and (c) multiple media studies employing the use of audio and visual materials. Last, important conditional factors such as learner experience have been identified across all categories.

First, the study of split attention and redundancy effects across several single format media studies have established consistent split attention and redundancy effects, as demonstrated by significantly superior learner performance, improved test scores, decreased error rates, quicker content processing times, reduced completion times and decreased levels of cognitive load. In contrast, given the situated nature of cognitive load research, specific levels of redundancy, split attention and/or levels of unintelligibility could not be expressed as formal prescriptive principles that are readily transferable to other learners and/or knowledge domains (Bobis et al., 1993; Chandler & Sweller, 1991, 1992; Purnell, Solman, & Sweller, 1991; Tarmizi & Sweller, 1988).

Second, similar split attention and redundancy effects have been studied in instructional situations involving two modes of instructional delivery, i.e., high complexity computer training with computer plus manual approaches vs. integrated manual or CBI only. Findings supported single media format studies and identified that instructional delivery strategies that utilize two pieces of instructional material may be detrimental to learning when more complex knowledge is being learned (Bobis et al., 1993; Cerpa, Chandler, & Sweller, 1996; Chandler & Sweller, 1992, 1996; Purnell et al., 1991).

Third, studies that incorporate both visual and auditory content have made a distinction between principles related to splitting the learner's attention between auditory and visual information (dual channel coding) and those related to split attention and redundancy effects in one channel (e.g., print) (Baddeley, 1992; Kalyuga et al., 1999; Reichle, Carpenter, & Just, 2000). In this context, both auditory and visual information may be used to expand working memory, while ameliorating audio-visual split attention effects (if any) and further benefit form prior strategies that limit split attention and redundancy effects (Kalyuga et al., 1999; Mayer, Heiser, & Lonn, 2001; Mayer & Moreno, 1998; Moreno & Mayer, 1999, 2002; Tindall-Ford, Chandler, & Sweller, 1997).

Last, in addition to the structure of human memory and distinct dimensions of cognitive load, learner experience and the ability of the instructional designer to correctly categorize how intrinsic, extraneous and germane load will influence a given learner or group has been shown to have bearing on the effectiveness of cognitive load theory driven design processes. That is, because a given instructional format is in part dependent on the experience of the learner, a format designed for a low level learner may not be suitable for a high level learner, with the opposite also holding true for a higher level learner. Such findings have provided support for the need to design instruction and instructional processes to the level of experience of the learner and that instruction that fails to do so may present with deleterious effects (Kalyuga, Ayres, Chandler, & Sweller, 2003; Kalyuga et al., 1998; Pollock et al., 2002; Renkl & Atkinson, 2003; Yeung, 1999; Yeung, Jin, & Sweller, 1997).

Cumulatively, prior studies have provided powerful evidence indicating that material should typically be presented without redundant features, and that materials that cannot be understood in isolation should be physically integrated. Second, self-explanatory, integrated diagrams are presumed superior when redundant and incidental materials are removed. Third, split attention and redundancy effects are equally applicable to multimedia instructional modalities that incorporate dual channel strategies. Fourth, learning and transfer are both favored by strategies that eliminate split attention and redundancy in technical areas and last, conditional factors such as learner experience must be accounted for within a given knowledge domain.

Purpose of the study, Hypotheses and Research Questions

The purpose of this study was to test the effectiveness of realistic integrated instructional materials designed to control redundancy and split attention in the teaching of complex Orthopedic Physical Therapy skills. Integrated materials were compared to non-integrated materials and subjective ratings of cognitive load, post-instruction written test scores, post-instruction psychomotor performance, and time to complete specific tasks were assessed. The following hypotheses were tested:

1. Participants who receive integrated instructional formats will achieve higher written posttest scores as compared to control group participants who receive non-integrated instructional formats.
2. Participants who receive integrated instructional formats will report lower subjective ratings of cognitive load as compared to control group participants who receive non-integrated instructional formats for both post instruction and post psychomotor performance.
3. Participants who receive integrated instructional formats will achieve higher performance scores on the performance of manual physical therapy skills as compared to control group participants who receive non-integrated instructional formats.
4. Participants who receive integrated instructional formats will have lower task completion times (instructional unit and examination) as compared to control group participants who receive non-integrated instructional formats.

In an attempt to identify the applicability of cognitive load theory constructs to a previously unexamined knowledge domain (Physical Therapy) and from the perspective of both cognitive and psychomotor performance, research questions that were examined in this study were as follows:

1. Are redundancy and split attention principles derived from Cognitive Load Theory transferable to the knowledge domain of manual physical therapy?
2. Will instructional materials designed in accordance with cognitive load theory design principles positively influence learner attitudes towards instruction?
3. Will the management of redundancy and split attention affect psychomotor performance?
4. What aspects of the psychomotor skills are transferred immediately following instruction; accurately without practice and without feedback?

Method

Participants

Forty-one graduate program physical therapy students were recruited on a voluntary basis and scheduled from within the Department of Physical Therapy at a large Midwestern university (Integrated instruction N=9, Nonintegrated instruction N=8) and from within the Program in Physical Therapy at a second, but smaller Midwestern university (Integrated instruction N=12, Nonintegrated instruction N=12).

Materials

Two questionnaires, two instructional units of equivalent content, a psychomotor performance rubric, a date/time log, protocol instructions and participant instruction were developed and reviewed by four instructors and piloted on six advanced students. Both instructional units were based on an actual curricular unit of instruction and the content was directly applicable to clinical practice with the exception of only presenting a single technique in the stimulus materials.

Non-integrated instructional unit

The non-integrated instructional unit contained a brief introduction and two short knowledge sections. Section one provided a brief introduction to the principles of orthopedic provocation and alleviation (techniques used to increase or decrease patient symptoms based on patient movement, positions, or manual contact). Section two described the process for performing a specific provocation and alleviation test. Specifically, the procedure presented in the units of instruction required a series of appropriately sequenced steps that could be used to help clinically localize the primary anatomical region of dysfunction for an orthopedic patient complaining of generalized low back, pelvic and leg pain with weight shifting onto the painful extremity (leg).

Integrated instructional unit

Sections and content were equivalent, though message design attributes for the integrated instructional unit sought to eliminate all redundancy and split attention effects. Specifically, content was the same, though message design attributes for the integrated instructional unit subscribed to cognitive load theory design practices, i.e., content that was unintelligible in isolation was integrated and redundant information was completely eliminated.

Instruments

The post-instructional questionnaire was used to collect participant reported educational and biographical data (age, gender, GPA, and prior academic degrees), and a subjective rating of the difficulty of the instructional materials based on the prior literature (Kalyuga, Chandler, & Sweller, 2000; Paas, E. Tuovinen, Tabbers, & van Gerven, 2003). Finally, the questionnaire asked the participant to rate attitudes towards learning (quality, effectiveness, relevance and confidence). Additionally, the post-psychomotor task instructional performance questionnaire asked the participant to rate the difficulty of the psychomotor task performance using the same scale. The delayed written-post test consisted of 18 questions designed to assess specific content features of the instructional units and the posttest psychomotor rubric was used to evaluate the psychomotor performance of each participant.

Procedure

All participants were randomly assigned to one of two treatment groups. In all, 41 participants successfully completed the treatments across 11 data collection sessions across 11 data collection sessions (average number of participants per group M=3.7). After the written posttest, participants were escorted to a separate laboratory designated for the psychomotor assessment, which prohibited participants from overhearing other participants as they completed the psychomotor assessment.

Results

The four hypotheses were evaluated using a multivariate analysis of variance and the significance level was set at alpha = .05. Additionally, no consequential violations of normality and homogeneity of variance were observed. Educational and biographical data were analyzed and no significant main effect was found; the data sets from the two institutions were pooled for the analyses. The MANOVA yielded an overall significant difference (Omnibus F) between the integrated and non-integrated groups, Pillai's Trace: $F(6, 34) = 6.213$, $p < .001$, ES = .52. Descriptive statistics for both groups are presented in Table 1.

A main effect was found for written posttest scores, $F(1,39) = 16.564$, $p < .001$, $MS_e = 2.12$, ES = .30. Participants who received the integrated instructional format achieved significantly higher written posttest scores (M = 16.00) as compared to control group participants who receive the non-integrated instructional format (M = 14.15) as predicted by the first hypothesis.

Table 1. *Descriptive statistics for both groups: primary hypotheses.*

Dependent Variables	N	Instructional Format: Non-Integrated	Instructional Format: Integrated
		20	21
Exam total score[1]	M	14.15	16.00
	SD	1.76	1.10
Cognitive load rating one – instruction[2]	M	3.35	2.71
	SD	0.81	0.85
Cognitive load rating two - technique[2]	M	3.50	2.62

	SD	0.95	1.07
Psychomotor rubric total score[3]	M	30.85	39.76
	SD	6.05	4.44
Time to complete instructional unit[4]	M	20.15	19.71
	SD	6.13	6.55
Time to complete written examination[4]	M	16.95	18.81
	SD	3.14	3.56

Notes
1. Possible range for exam score (0-18)
2. Possible range for cognitive load ratings one and two (1-7)
3. Possible range for psychomotor rubric score (0-44)
4. Possible range for instruction and written examination times (0-30 minutes)

Additional analysis was conducted to assess content structure scores as identified by low element interactivity and complexity or high-element interactivity and complexity in the following categories: (a) identical content (low element interactivity and complexity), (b) redundant content in the non-integrated unit of instruction (high-element interactivity and complexity) and (c) split attention content in the non-integrated unit of instruction (high element interactivity and complexity).

Univariate analyses of content structure scores revealed that the integrated instruction group (M = 5.71) scored significantly higher than the non-integrated instruction group (M = 5.20) on the written posttest when the content was not presented with redundant format, $F(1,39) = 6.82$, $p = .013$, $MS_e = .34$, ES = .15, and when the content did not have split attention features (M = 4.81), $F(1,39) = 9.73$, $p = .003$, $MS_e = .97$, ES = .20; as compared to the non-integrated instruction group (M = 3.85). No differences were noted with identical presentation formats between groups, observed power value = .33 (see descriptive statistics, Table 2).

Table 2. D*escriptive statistics for exam scores as a function of content structure.*

Content Structure		Instructional Format	
		Non-Integrated	Integrated
	N	20	21
Identical content[1]	M	5.10	5.48
	SD	0.79	0.75
Redundant content[2]	M	5.20	5.71
	SD	0.77	0.46
Split attention content[3]	M	3.85	4.81
	SD	1.18	0.75

Notes
Possible range for exam scores in each category (0-6)
1. Content was identical in both treatments (no redundant or split attention features)
2. Content contained redundant information in the non-integrated treatment
3. Content was unintelligible without mental integration in the non-integrated treatment

A main effect was found for subjective ratings of cognitive load measured after the completion of the instruction $F(1,39) = 6.02$, $p = .019$, $MS_e = .69$, ES = .13, and after the completion of the psychomotor performance task $F(1,39) = 7.76$, $p = .008$, $MS_e = 1.02$, ES = .17 supporting hypothesis two. Participants who received the integrated instruction format reported significantly lower subjective ratings of cognitive load measured after instruction (M = 2.71), as compared to control group participants who received the non-integrated instruction format (M = 3.35), as predicted. Additionally, participants who received the integrated instruction format reported significantly lower subjective ratings of cognitive load measured after psychomotor performance (M = 2.62), as compared to control group participants who received the non-integrated instruction format (M = 3.50).

A main effect was found for psychomotor performance scores $F(1,39) = 29.15$, $p < .001$, $MS_e = 27.90$, ES = .43. As predicted by hypothesis three, participants who received the integrated instruction format achieved significantly higher rubric scores on the performance of manual physical therapy skills (M = 39.76), as compared to control group participants who received the non-integrated instruction format (M = 30.85).

The psychomotor rubric was broken into three distinct sections: evaluation, application and comprehension. Univariate analyses of psychomotor performance scores revealed that the integrated instruction group scored significantly higher on the evaluation section (M = 7.10): $F(1,39) = 20.23$, $p < .001$, $MS_e = 8.91$, ES = .34; and the application section (M = 28.67): $F(1,39) = 13.95$, $p < .001$, $MS_e = 13.37$, ES = .26; of the rubric as compared to control group participants who received the non-integrated instruction format (M = 2.90 and 24.40 respectively). No significant differences were noted on the comprehension section between groups (observed power value = .37). Descriptive statistics for evaluation, application and comprehension rubric scores are presented in Table 3.

Table 3. *Descriptive statistics for the psychomotor rubric: evaluation, application and comprehension.*

Rubric Sections		Instructional Format	
		Non-Integrated	Integrated
	N	20	21
Evaluation[1]	M	2.90	7.10
	SD	2.45	3.43
Application[2]	M	24.40	28.67
	SD	4.88	1.85
Comprehension3	M	3.55	4.00
	SD	1.23	0.00

Notes
1. Possible range for scores (0-10)
2. Possible range for scores (0-30)
3. Possible range for scores (0-4)

Hypothesis four stated that "Participants who receive integrated instructional formats will have lower task completion times (instructional unit and examination) as compared to control group participants who received non-integrated instructional formats". There were no significant differences between the groups on time spent to complete the instructional unit or the written examination. These two variables had observed power values of .06 and .41, respectively.

In an attempt to identify the applicability of cognitive load theory constructs to teaching manual physical therapy skills, four research questions were examined in this study. The first research question sought to determine if redundancy and split attention principles derived from cognitive load theory were transferable to the teaching of manual physical therapy skills. Statistically significant results in the expected direction for three of the four hypotheses provided support for the transferability of cognitive load theory design principles to the knowledge domain of manual physical therapy in this study. Specifically, the integrated instruction group achieved significantly higher written exam scores (M = 16.00): $F(1,39) = 16.564$, $p < .001$, $MS_e = 2.12$, ES = .30, as compared to the non-integrated instruction group (M = 14.15). Additionally, the integrated instruction group reported significantly lower subjective ratings of cognitive load after the completion of the instruction $F(1,39) = 6.02$, $p = .019$, $MS_e = .69$, ES = .13, (M = 2.71 and M = 3.35, respectively) and after the completion of the psychomotor performance task $F(1,39) = 7.76$, $p = .008$, $MS_e = 1.02$, ES = .17, (M = 2.62 and M = 3.50, respectively). Finally, the integrated instruction group (M = 39.76) achieved significantly higher psychomotor performance scores $F(1,39) = 29.15$, $p < .001$, $MS_e = 27.90$, ES = .43, as compared to control group participants who received the non-integrated instruction format (M = 30.85).

The second research question sought to discover if instructional materials designed in accordance with cognitive load theory design principles would positively influence learner attitudes towards instruction. The integrated instruction group reported lower subjective ratings of cognitive load for the written post test (M = 2.71): $F(1,39) = 6.02$, $p = .019$, $MS_e = .69$, ES = .13 and on psychomotor performance (M = 2.62), as compared to the non-integrated instruction group (M = 3.35 and 3.50 respectively). In contrast, there was no overall significant difference in general attitudes towards instructional format between the non-integrated group (M = 1.64) and integrated group (M = 1.74), with both groups reporting relatively high satisfaction with their respective instructional materials.

The third research question sought to determine if the management of redundancy and split attention will affect psychomotor performance. Relative to psychomotor performance, the integrated group scored significantly higher (M = 39.76) than the non-integrated group (M = 30.85) on the psychomotor task performance, $F(1,39) = 29.15$, $p < .001$, $MS_e = 27.90$, ES = .43.

The fourth research question asked what aspects of the psychomotor skills were transferred immediately following instruction. Overall, the integrated group scored significantly higher (M = 39.76) than the non-integrated group (M = 30.85) on the psychomotor task performance, $F(1,39) = 29.15$, $p < .001$, $MS_e =$

27.90, ES = .43. Specifically, psychomotor skills related to technique evaluation (M = 7.10): $F(1,39) = 20.23$, $p < .001$, $MS_e = 8.91$, ES = .34; and the application section (M = 28.67): $F(1,39) = 13.95$, $p < .001$, $MS_e = 13.37$, ES = .26 were transferred with greater efficiency, without practice and without feedback in the integrated instructional group, as compared to control group participants who received the non-integrated instruction format (M = 2.90 and 24.40 respectively). No significant differences were noted on the comprehension section between groups in this study.

Discussion and Conclusions

In this study, there was an overall significant difference (Omnibus F) between the integrated and non-integrated treatments and an overall moderate effect size of .52 was observed. Significant results were found in the expected direction for the hypotheses predicting higher achievement on the written examination scores, lower ratings of cognitive load following instruction and technique phases, and higher performance on the psychomotor task by the integrated treatment group, as compared to the non-integrated treatment group. There were no significant differences noted in terms of the time required to complete instruction or written examinations between groups.

Hypothesis one

Hypothesis one predicted that participants who received the integrated instructional format would achieve higher posttest scores as compared to control group participants. The primary variables under assessment were written posttest scores, which entailed the further analysis content structure scores. The results for cumulative scores and content structure scores indicated that there was a significant difference between the two instructional conditions in the expected direction with the integrated instruction group scoring significantly higher. These findings suggest that the instructional complexity, interactivity of elements, and novelty of the content were capable of placing an appreciable load on the learner's available cognitive resources. These results further suggest that the integrated treatment allowed for GCL by reducing ECL as a function of sound design practices. Conversely, these results also suggest that the traditional treatment (non-integrated format) sufficiently increased ECL and sufficiently limited GCL which prevented participants from developing the appropriate schema and understanding of the content. The reduction of total cognitive load via the management of ECL is perhaps the most prominent cognitive load management principle and is consistent with findings identified in prior research (Bobis et al., 1993; Chandler & Sweller, 1991, 1992; Marcus, Cooper, & Sweller, 1996; Purnell et al., 1991; Tarmizi & Sweller, 1988).

Content structure scores

Additional analysis was conducted to assess content structure scores between groups. In conditions where the instruction required mental integration (split attention effect) for understanding or in situations where instructional materials were presented with redundant features (redundancy effect) the integrated-instructional group scored significantly higher as compared to the control group on respective test questions. Because complex learning situations composed of several highly interrelated elements will create the heaviest load on working memory, the differences in content structure scores between groups provides further support for the preliminary findings. That is, the content containing redundant or split attention features represented a discernable difference between groups in terms of the number of discrete elements that participant's were required to maintain and manipulate simultaneously in working memory. Furthermore, the lower performance demonstrated by the non-integrated instruction group suggests that the number of elements exceeded the processing abilities of working memory and sufficiently limited germane cognitive load. Conversely, the higher performance demonstrated by the integrated instruction group suggests that the number of elements did not exceed the processing abilities of working memory as a function of sound instructional and message design practices. Finally, as would be expected, in situations where it was not necessary for the learner to integrate divergent sources of information or process redundant information, there was no difference between the integrated and non-integrated formats (Sweller & Chandler, 1994; Sweller et al., 1998).

Additional Considerations

As a function of study design, some meta-cognitive processes were under the direct control of the participants and subject to individual strategies that were in part a function of intrinsic cognitive load. To this end, learners may or may not have utilized advantageous metacognitive strategies. Furthermore, because the diagrams contained in both treatments reflected procedural sequences as a function of the clinical nature of localization testing, both instructional formats would have offered the learner an isolated step by step illustration of task performance and an overall illustration of task performance. However, while each isolated step and the overall strategy driven process could have been derived from either instructional format, the redundant and divergent sources of information contained in the non-integrated group combined with increased extraneous load decreased GCL would have made it difficult for the non-integrated treatment group to form such understandings. Thus, it is plausible that participant access and execution of more and less productive metacognitive strategies would have varied between groups as a function of instructional format and available cognitive resources.

In the context of procedural nature of the treatment materials and in consideration of more recent contributions to cognitive load theory, the integrated group may have chosen to learn or memorize the individual steps in isolation (isolated elements approach or serial processing) before attempting to integrate the entire process (Pollock et al., 2002). While the claim that the integrated treatment group utilized such strategies is speculative, future studies might query the participants to determine what type of metacognitive strategies they used for the different tasks and/or choose a multi-stage approach in order to manipulate intrinsic load.

Hypothesis Two

Hypothesis two predicted that participants who received the integrated instructional format would report lower subjective ratings of cognitive load as compared to those receiving the non-integrated format. The primary variables under assessment were subjective ratings of cognitive load reported after completing both the instructional unit and psychomotor assessment. The integrated-treatment group reported significantly lower subjective ratings of cognitive load post-instruction and post-psychomotor assessment as predicted.

These significantly lower subjective ratings were well aligned with the significantly higher objective performance measures achieved by the integrated treatment group. Additionally, while the use of subjective ratings of cognitive load were not identified in prior research in the context of psychomotor assessment or the performance of manual physical therapy skills, the present findings suggest that such measures can be extended to the performance of psychomotor tasks. Specifically, significantly lower subjective ratings of cognitive load reported by the integrated treatment were correlated with significantly higher psychomotor assessment scores as discussed below.

Hypothesis Three

Hypothesis three predicted that participants who received the integrated instructional formats would achieve higher performance scores on manual physical therapy tasks. The primary variable under assessment was cumulative rubric score for performance of manual physical therapy skills. On this task, the integrated-treatment group scored significantly higher on total psychomotor performance in the expected direction.

As a function of the clinical nature of localization testing and its practical applicability to clinical practice, the psychomotor rubric consisted of three distinct sections: (a) comprehension, (b) application and (c) evaluation. When comparing psychomotor scores between groups, the integrated group scored significantly higher on the evaluation section and the application section of the rubric, with no significant differences noted on the comprehension section. These findings suggest that both groups understood the concepts presented in their respective instructional treatments, though only the integrated treatment group was able to demonstrate proficiency on psychomotor tasks performance. These specific findings could be attributed to both the content structure of the two treatments and the level of complexity of the content itself. Specifically, the presentation of evaluation and application content structure was very conducive to diagrammatic presentation and in fact, the patient positioning phases (application and evaluation) and the application phases (procedural steps) were both presented in diagrammatic formats. In the non-integrated treatment, the participants needed to integrate the information to understand the procedure, a constraint that was not present in the integrated treatment. Plausible explanations for superior performance demonstrated by the integrated treatment group on the application and evaluation sections were specifically discussed above.

In terms of superior performance demonstrated by the integrated treatment group on psychomotor tasks, Romiszowski (1993) identified that psychomotor learning typically involves the acquisition of both skills and knowledge in which he identifies knowledge as “information stored in the performer’s mind or available to the performer in some reference source” and skill as “actions (intellectual as well as physical) which the performer executes in a competent manner in order to achieve a goal” (p. 130-131). Romiszowski additionally discusses psychomotor performances across a continuum of types of knowledge content in which he notes the distinctions between “reproductive skills” that entail repetitive and automated actions and “productive skills” that entail the use of adaptive strategies and reasoning skills. This study employed psychomotor tasks that are consistent with Romiszowski's definition of "productive skills" as the participants had little time to address repetition or automation and were required to problem solve and adapt strategies or make clinical decisions during the psychomotor assessment phase (Romiszowski, 1993).

This particular type of skill has also been studied by Anderson (1983) in his development of the Adaptive Control of Thought (ACT) model, which has been directed towards understanding procedural knowledge linked to cognitive skills relevant to decision making and problem solving or productive skills. ACT describes that "productions provide the connection between declarative knowledge and behavior"(Anderson, 1983). Relative to this study, Anderson's explanation of the link between declarative knowledge and behavior helps to offer further explanation for the significantly superior performance on task performance by the integrated instruction group as compared to the non-integrated instruction group. Specifically, given the significantly superior performance demonstrated by the integrated instruction group, the non-integrated instruction group would have likely experienced a waterfall failure effect in that they were unsuccessful in transferring the necessary declarative knowledge and problem solving schema to long term memory that were required for successful task performance.

Hypothesis Four

Hypothesis four predicted that participants who received the integrated instructional formats would have lower task completion times. The primary variables under assessment were task completion times for the instructional unit and the written examination. There were no significant differences between the groups on time spent to complete the instructional unit or the written exa mination. These two variables had observed power values of .055 and .408, respectively, which means that many more participants would have been needed to detect a significant difference, if it in fact existed. In contrast, Stem-and-Leaf Plots for the variable "Total Exam Time" in both the non-integrated and integrated instructional groups presented two data plots with extreme outliers relative to all other data, which contained no extreme outliers. Specifically: non-integrated format (1.00 extreme. >/= 26.0) and integrated format (1.00 extreme, >/= 30). When additional analysis was performed with these two extreme outliers removed, Total Exam Time was reported as $F(1, 37) = 5.11$, $p = .03$, ES = .12. One plausible explanation for these finding could be attributed to sample size, as a much larger sample size may have not been so readily influenced by extreme outliers, if present. Additionally, another plausible explanation is that the integrated instruction group had to give little mental effort, while the non-integrated group felt overwhelmed and did not give the additional effort needed to overcome the limitations of the materials needed to promote learning with understanding. Future studies might query participants to determine affective or motivational responses to varied instructional formats in order to better understand underlying cognitive reasoning.

Research Questions

The first research question asked if redundancy and split attention principles derived from Cognitive Load Theory were transferable to the knowledge domain of manual physical therapy. In this study, the statistically significant results in the expected direction for three of four hypotheses provide support for the transferability of cognitive load theory design principles to the teaching of manual physical therapy.

The second research question asked if instructional materials designed in accordance with cognitive load theory design principles would positively influence learner attitudes towards instruction. In this study, statistically significant results in the expected direction indicated that attitudes as a function of subjective ratings of cognitive load reported by the integrated instruction group were positively influenced as compared to the non-integrated instruction group. However, general attitudes towards instructional formats did not identify an overall significant difference between the integrated and non-integrated groups. In this context, both groups perceived both units of instruction rather favorably which for the non-integrated treatment group was in contrast to both objective measures and subjective ratings of cognitive load. In this study, the short instructional time might have also influenced the subjective ratings while longer instructional periods noted in a traditional classroom setting might have provided different findings.

The third research question asked if the management of redundancy and split attention would affect psychomotor performance. Statistically significant results in the expected direction indicated that cognitive load theory design principles were successfully extended to the performance of manual physical therapy skills. Additionally, no differences were found in conditions involving low element complexity and interactivity, such as with conditions that would not be expected to tax working memory resources.

The fourth research question asked what aspects of the psychomotor skills are transferred immediately following instruction; accurately without practice and without feedback. Study findings suggest that superior performance on both cognitive and psychomotor performance can be obtained as a function of instructional message design principles that eliminate split attention and redundancy effects.

Applications to Physical Therapy

Relative to practical and clinical significance is the observation that the integrated treatment group achieved an 89% on the examination and 90% on the psychomotor assessment (practical examination), while the non-integrated treatment group achieved a 79% and 70% respectively, the latter grades would be considered failing by program standards. Additionally, practical examinations (formal psychomotor assessments) are often limited to a single "re-take" opportunity prior to course and/or program dismissal. To this end, the differences in scores from a curricular perspective as a function of instructional format, as well as the direct applicability of the treatment materials to real world clinical practice are salient features of this study.

Relative to cognitive load theory, distinctions between the reduction of ECL and the "freeing up" of GCL via message design strategies and the external facilitation of GCL via schema driven strategies could be better delineated via multiple experiment designs. Second, the applicability of isolated and interacting elements approaches to cognitive and psychomotor tasks should be entertained. Last, future research should attempt to determine to what extent (if any) metacognitive strategy selection is influenced by manipulating various facets of cognitive load and the effects that isolated and interacting elements approaches for both cognitive and psychomotor tasks.

Conclusions

This study used ecologically valid materials in a realistic classroom setting. As predicted, the participants receiving the integrated-instructional materials scored significantly higher on the written posttest. This result suggests that designers can increase the germane cognitive load by reducing the extraneous cognitive load through good instructional and message design practices. This study extended the prior research by examining the effect of lowered extraneous cognitive load on the performance of a psychomotor task. The significant increase in performance by the integrated-materials treatment participants suggests that psychomotor performance is also enhanced by an increase in germane cognitive load capacity.

These findings suggest that instructional designers should reduce designs that create split-attention and redundancy. In addition, graphics should be created using an integrated approach suggested by Sweller (1999) that further reduces extraneous cognitive load. With complex information, it is apparent that instructional designers must manage extraneous cognitive load to afford learners the opportunity to develop appropriate schemata. The findings from this study combined with the robust nature of cognitive load theory in general, warrants further investigation of cognitive load principles in the design of Physical Therapy instructional materials and the application of cognitive load principles to psychomotor performance.

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