1. Cover sheet

Title:
Cognitive load theory for training health professionals in the workplace: A BEME systematic review of studies among diverse professions

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Abstract:
Cognitive load theory (CLT) is a learning theory focused on the limits of working memory. CLT describes three types of cognitive load. *Intrinsic* load arises from the inherent difficulty of essential components of a learning task. *Extraneous load* arises from nonessential components associated with a learning task. Germane load occurs when learners use cognitive resources to manage intrinsic load by forming learning schemata and information "chunks". According to CLT, when the amount of cognitive load exceeds working memory's limits, learners become overwhelmed, limiting opportunities for learning. CLT is of increasing interest to researchers and practitioners within health professions education. A few useful reviews of CLT have been published, but these have addressed the role of CLT in health professions education broadly. We seek to build upon these prior reviews by performing a scoping review using a rigorous, systematic search protocol, specifically focused on studies of CLT in workplace settings. To expand the scope of our findings and learn lessons from outside the health professions, we will include studies performed both within and outside of the health professions. In addition to informing ongoing theoretical debates regarding CLT, we anticipate that our review will produce a useful summary of studies using CLT in workplace settings, as well as a list of "best practices" for studying and applying CLT in health professions workplaces. We believe the resulting publication will of practical benefit to researchers and educators in the health professions.

Source of support: This effort will be supported in part by a grant from the Society of Directors of Research in Medical Education (SDRME).

2. Background

Our review seeks to answer three primary research questions as described below. Following these questions is a discussion of background information that will clarify context and importance of these questions.

(1) How do studies of cognitive load theory (CLT) in the workplace contribute to, or conflict with, theoretical tenets of CLT?
(2) What practical implications for workplace teaching, curricular design, and educational research in the health professions can be drawn from included studies?
(3) How has the study of CLT differed in health professions versus non-health professions settings, and what lessons can be learned from these differences?

Developed by Sweller and colleagues in 1988[1], CLT is a learning theory focused on working memory[2]. As opposed to capacity for sensory input and long-term memory, which are both theoretically infinite, working memory can process only a finite number of items, or pieces of information, at a given time. Under ideal conditions, this is thought to be seven (+/- 2) items at any given time, and less when active information processing is occurring. When the degree of cognitive load exceeds the limits of working memory, opportunities for learning are reduced. Because of its limited capacity, CLT envisions WM as the primary bottleneck for learning and therefore an area of primary importance for design of curricula and learning activities.

CLT describes three types of cognitive load [2]. Each of these load types uses space in working memory in an additive fashion. *Intrinsic load* (IL) arises from the inherent difficulty of a task, so that a complex task will require greater use of WM than a simple task. IL is highly dependent on learners' prior knowledge and experience. *Extraneous load* arises from nonessential components of a learning task or learning environment that require working memory resources to process. For example, if a lecturer includes an overly complex or poorly designed slide in her presentation, learners will use working memory resources to try and understand the slide itself (thus causing extraneous load), instead of trying to understand the actual topic at hand (which produces intrinsic load). Another example of extraneous load would be distractions in the learning environment that divert working memory away from the actual learning topic at hand. Finally, *germane load* arises from learner's efforts to manage their intrinsic load; that is, to contextualize the topic at hand with prior knowledge and to create learning schema or chunks that can be transferred to long-term memory (and thus free up working memory resources for processing further information). Some see germane load as a marker for learning[3], while others envision germane load as a subset of intrinsic load[4]. In either case, maximal germane load is the ultimate goal of a learning encounter according to CLT. The authors believe that to maximize germane load, extraneous load must be minimized, and intrinsic load should be tailored to the prior experience of the learner. We speculate that either very high or very low IL could negatively impact GL (very high IL will overwhelm working memory resources, while very low intrinsic load may provide "nothing to learn").

Each type of CL represents a grouping of activities that are thought to occur through the working memory of a learner and are not directly measurable. Techniques used to measure cognitive load include self-rating questionnaires (including single item self-rating of overall mental effort[5, 6] and multiple items intended to measure the different types of cognitive load[4, 7, 8]); response time to a secondary task[6]; physiological measurements (such as task-evoked pupillary responses, heart rate variability, and skin conductivity)[9] ; and even functional MRI[10]. It is not yet known which measurement technique is most accurate, owing to lack of a "gold standard" that directly measures cognitive load. For educational research purposes, self-rating instruments such as those published by Paas[5] and Leppink[4, 7] seem most feasible (additionally, our group has completed a study to design and test a self-rating instrument, which is now In Press with *Medical Education*[11].

Sweller originally developed CLT through the study of high school students learning mathematics[1]. In this work, he found that conventional problem-solving through means-end analysis imposed higher cognitive load than did non-goal directed learning. Since that time, the theory has grown and matured significantly[12]. There is growing interest in applying the theory to health professions education (HPE), a field to which experts agree CLT is well-suited[3], in part due to the complexity of training in these professions. Although schools are developing increasingly integrated approaches to HPE, most programs tend to favor classroom and/or small-group learning early in training, with increasing immersion in workplace learning later in training. While CLT likely applies to learners across this spectrum, we believe that it is most highly applicable in workplace learning settings, where the complexity and amount of information being processed is likely to be higher, and decisions often have to be made more quickly. We therefore designed this systematic review to better characterize the role of CLT in HPE workplace learning. We have identified three prior reviews discussing application of CLT to HPE. In 2010 van Merrienboer and Sweller summarized recommendations to reduce extraneous load and to optimize intrinsic and germane load[2]. In 2014 Young (an author on this protocol) and colleagues summarized CLT tenets as applied to medical education[3]. In 2015, Fraser and colleagues summarized applications of CLT to design of medical simulations[13].

Each of the above reviews has synthesized and summarized important aspects of CLT as applied to HPE and our study will build upon these reviews in four ways. First, we will employ a systematic search strategy, which none of the above reviews has reported. This will maximize the likelihood of identifying impactful and relevant studies. Second, we will focus specifically on studies performed within the workplace, which will facilitate a summary of the evidence in this area and targeted recommendations for future teaching, curricular design, and research in HPE workplace learning. Third, we will include studies across the spectrum of the health professions, rather than limiting to our familiar setting of medicine. This will increase the diversity of included studies and generalizability of findings that we synthesize. Finally, we suspect that CLT has been studied in fields outside of HPE, and our review will seek to identify such studies. Including studies outside of the health professions may yield additional insights, just as study of the aviation industry has benefitted the field of anesthesiology[14].

Revisiting our research questions described above, we expect our review to contribute to the literature in three primary ways. First, our review will further theoretical understanding of CLT by addressing two debates that continue among CLT experts. Chief among these are best method(s) for measuring cognitive load, and whether germane load should be considered as its own type of cognitive load, or whether it is simply a part of intrinsic load. Second, we will be able to provide practical recommendations (based on synthesis of included studies) that health professions educators can use as they plan research, teaching, or curricula related to CLT in HPE workplace settings. Third, our review may identify areas of synergy between HPE and other professions as they use CLT in the workplace. Both CLT [15] and workplace learning[16] are of significant and escalating importance to HPE. Although CLT was originally developed in classroom learning settings with much more junior learners, we appreciate substantial opportunities for intersection of CLT and workplace learning, and we believe our review will be of substantial impact to both.

3. Review topic/question(s), objectives and key words

Our systematic review is intended to accomplish the following objectives:

(1) Identify, describe, and synthesize quantitative and qualitative studies using CLT in workplace settings among health professions and non-health professions learners and trainees
(2) Summarize differences in approaches for studies in the health professions versus non-health professions
(3) Summarize theoretical implications of these studies as they pertain to CLT
(4) Generate practical recommendations for using CLT for workplace learning in terms of teaching, curricular design and educational research.

As previously described, our systematic review is intended to address the following three research questions:

(1) How do studies of cognitive load theory (CLT) in the workplace contribute to, or conflict with, theoretical tenets of CLT?
(2) What are practical implications for educational research and curricular design in the health professions that can be drawn from included studies?
(3) How has the study of CLT differed in health professions versus non-health professions settings, and what lessons can be learned from these differences?

Definitions:
Cognitive load theory refers to the specific learning theory developed by Sweller and colleagues[1] described previously.

- *Workplace* refers to the applied setting in which trainees or learners are involved in activities that are authentic partial or complete representations of tasks and/or environments in which their future profession will be applied. A study of nursing students learning to place peripheral intravenous catheters would be an example of a task-oriented workplace learning study. A study of medical student learning during an inpatient ward rotation would be an example of an environment-oriented workplace learning study. The term *workplace* specifically excludes purely didactic learning settings such as lectures, or small groups that lack any authenticity to future professional practice environment. Alternatively, a study *simulating* an authentic workplace task or environment would be included.
- *Health professions* include medicine, nursing, dentistry, pharmacology, physical therapy, occupational therapy, chiropractic medicine, veterinary medicine, optometry, nutrition, radiology technology, blood-banking, and laboratory medicine.
- *Non-health professions* include any other professions, for example engineering, accounting, law, or teaching. We define a profession as 'a field requiring a specific degree and licensure to practice in the field'.

The five most relevant key words for the study are:

(1) Cognitive load
(2) Cognitive load theory
(3) Mental effort
(4) Mental workload
(5) Workplace

4. Search sources and strategies

We plan to search eight databases to maximize the likelihood of identifying relevant studies within and outside the health professions. These databases were selected because they cover a wide variety of health and non-health professions. Because cognitive load theory and cognitive load are fairly specific topics, we were able to create search strings using broad search terms. These search terms were developed by consensus among our research team which includes experts/developing experts in CLT (JQY, JLS), a PhD medical librarian (LAM), and world-renowned experts in medical education (PSO'S, OTC).

Databases and proposed search terms are as follows:

Database	**Search Terms**
PubMed	("cognitive load" OR "cognitive load theory" OR "mental effort" OR "mental load" OR "human channel capacity" OR "mental workload") AND ("education, professional" OR "professional education" OR education [sh] OR educat* OR training OR trainee* OR students [mesh] OR student* OR learner*)
PsycINFO	("cognitive load" OR "cognitive load theory" OR "mental effort" OR "mental load" OR "human channel capacity" OR "mental workload") AND (educat* OR education OR training OR trainee* OR student* OR learner*) in ANYWHERE *(limit to peer reviewed)*
ERIC	("cognitive load" OR "cognitive load theory" OR "mental effort" OR "mental load" OR "human channel capacity" OR "mental workload") AND (educat* OR education OR training OR trainee* OR student* OR learner*) in ANYWHERE
CINAHL	("cognitive load" OR "cognitive load theory" OR "mental effort" OR "mental load" OR "human channel capacity" OR "mental workload") AND (educat* OR education OR training OR trainee* OR student* OR learner*)
Scopus	("cognitive load" OR "cognitive load theory" OR "mental effort" OR "mental load" OR "human channel capacity" OR "mental workload") AND (educat* OR education OR training OR trainee* OR student* OR learner*) in Article, Title, Abstract, Keywords
Web of Science	("cognitive load" OR "cognitive load theory" OR "mental effort" OR "mental load" OR "human channel capacity" OR "mental workload") AND (educat* OR education OR training OR trainee* OR student* OR learner*) in TOPIC
IEEE Xplore Digital Library	"cognitive load" OR "cognitive load theory" OR "mental effort" OR "mental load" OR "human channel capacity" OR "mental workload" *(These must be entered individually under the 'Advanced Search' area of the IEEE Xplore website, rather than joined with Boolean terms in one line.)*
Google Scholar	allintitle: ("cognitive load" OR "cognitive load theory" OR "mental effort" OR "mental load" OR "human channel capacity" OR "mental workload") AND (education OR training OR trainee)

We will also:

- Search bibliographies of included studies
- Include any studies known to the investigators that are not returned via the search terms
- Contact several prominent authors in the field for guidance (e.g., Sweller, Paas, Leppink, van Merrienboer, van Gog, Naismith)
- Review the references of the relevant review articles, including those by Sweller, Young, and Fraser
- Continually monitor the literature for newly published relevant articles

Because studies using CLT could be published in numerous journals, we do not plan to hand-search any journal tables of contents. Grey literature will be identified through the inclusion of ERIC, PsycINFO, Scopus, Web of Science, and Google Scholar. We will not impose any restrictions in terms of publication date or language. If articles are recovered in languages not spoken by our study team, translation services will be sought. We will not restrict studies based on study design or publication type.

We will use Covidence, an online systematic review manager, to maintain our reference database. This is a new online program that has been designed specifically to facilitate systematic reviews. Holly Nishimura will search the databases, upload references to Covidence, and de-duplicate references.

5. Study selection criteria

After de-duplication of citations, we will review reference titles and abstracts. Two authors (JLS and PO) will review all titles, and, for titles suggestive relevance, abstracts, selecting references with likely relevance to inclusion and exclusion criteria. Full articles for selected abstracts will then be reviewed by both authors, with application of the following inclusion and exclusion criteria.

Inclusion criteria are as follows. **For a study to be included, it must meet criteria 1 AND 2 AND 3.**

1) *Study uses CLT or measures cognitive load*: study design explicitly uses CLT, *OR s*tudy measures cognitive load, mental effort, or mental workload
2) *Educational research study*: study or review includes learners/trainees/students with specific objective to assess process or outcomes of learning
3) *Workplace setting*: study occurs in an applied setting in which trainees or learners are involved in activities that are partial or complete representations of tasks and/or environments in which their profession is/will be applied

Exclusion criteria are failure to meet all three of the above criteria. The first two criteria will likely be straightforward. Whether a study involves a workplace setting may be the most challenging criteria to agree upon.

Studies meeting inclusion criteria will then undergo data extraction, as described below. Differences at any of the above steps will be resolved via consensus. If consensus cannot be obtained, another author (LAM) will assist with adjudication.

6. Procedure for extracting data

Two authors (JLS and PSO'S) will independently review and code all articles meeting inclusion criteria using the online systematic review manager Covidence. Differences in coding will be resolved via consensus. If consensus cannot be obtained, another author (LAM) will assist with adjudication.

Data to be extracted include the following:

1. Publication characteristics (i.e., publication type, journal, year, authors)
2. Country, state, location of study
3. Method of study identification (e.g., electronic, bibliography, expert recommendation,)
4. Population studied (health profession or not; specific profession)
5. Study aim (and whether this was implied or stated)
6. Study setting (specific activity, what type of workplace or simulation)
7. Is CLT the primary study frame (or are others present)
8. Inclusion/exclusion criteria
9. Study design, including presence or absence of control group and whether subjects were randomized
10. Was study qualitative or quantitative?
11. Was study design retrospective or prospective?
12. Did authors report *a priori* hypotheses?
13. Sample size
14. Data collection methods
15. Primary outcomes/themes studied and how they were measured
16. Intervention(s) and comparators
17. Methods used to measure cognitive load
18. Primary conclusions (with regard to both theoretical and practical implications of CLT)
19. Measure of study quality using Medical Education Research Study Quality Instrument (MERSQI) and/or BEME Quality Indicators (for quantitative studies) and Standards for Reporting Qualitative Research items[17] (for qualitative)
20. Conclusions or findings with regard to cognitive load theory

7. Synthesis of extracted evidence

Our primary goal is to broadly identify, review, and synthesize studies using CLT in the workplace. These goals are broad and do not address specific, focused questions that would be appropriate for such methods as a traditional systematic review or critical-realist review. Rather, we believe that the most appropriate review methodology is the scoping review. There are several potential purposes for scoping reviews, among them to "examine broad areas to identify gaps in the evidence, clarify key concepts, and report on the types of evidence that address and inform practice in a topic area"[18]. This broad overview of studies will enable us to address our three research questions (see section 3). As opposed to some scoping reviews, we will employ a rigorous search strategy (see section 4), inclusion and exclusion criteria (see section 5), and evaluation of study quality (see section 6).

Data extracted will be synthesized and presented both quantitatively and qualitatively. Search results and inclusion/exclusion data will be presented using a PRISMA-style search decision flowchart. Characteristics of included studies (i.e., data to be collected as per section 6) will be presented in tabular format. In addition to tabular presentation, synthesis will involve descriptively comparing, contrasting, and discussing studies and outcomes that address our primary research questions, as well as salient themes that become evident during the course of the review. Figures will be created if appropriate to better illustrate important themes.

The discussion section will include a narrative synthesis addressing each of the research questions, other themes identified during the course of the literature search, study limitations and knowledge gaps identified, and directions for future research.

8. Scoping search

We performed an initial search of the seven databases on September 28, 2015. The search strings and numbers of records identified are as follows:

Database	**Search Terms**	**Records identified**
PubMed	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (“education, professional” OR “professional education” OR education [sh] OR education)	278
PsycINFO	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) and (educat*) in ANYWHERE	1,296
ERIC	(“cognitive load” OR “cognitive load theory” OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) in ANYWHERE	778
CINAHL	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (educat*)	74
Scopus	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (educat*) in Article, Title, Abstract, Keywords	837
Web of Science	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (educat*) in TOPIC	720
IEEE Xplore Digital Library	("cognitive load" OR "cognitive load theory")	28
Total records		4,011
Duplicated records		1,306
Total records de-duplicated		**2,705**

We then searched the results for 11 papers that the search should have identified. Ten of these were present[2, 3, 6, 8, 13, 19-23]. The one study not present had not yet been indexed for PubMed[9]. We found that by adding terms related to learners, students, and trainees, that study was identified. We therefore decided to add these terms to our search strings (except for IEEE Xplore, for which we kept the simple search shown above as it returned more references).

We repeated our search using the following revised search strings on October 6, 2015. This produced the following numbers of records:

Database	**Search terms**	**Records identified**
PubMed	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (“education, professional” OR “professional education” OR education [sh] OR educat* OR training OR trainee* OR students [mesh] OR student* OR learner*)	475
PsycINFO	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (educat* OR education OR training OR trainee* OR student* OR learner*) in ANYWHERE *(limit to peer reviewed)*	1,841
ERIC	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (educat* OR education OR training OR trainee* OR student* OR learner*) in ANYWHERE	777
CINAHL	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (educat* OR education OR training OR trainee* OR student* OR learner*)	135
Scopus	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (educat* OR education OR training OR trainee* OR student* OR learner*) in Article, Title, Abstract, Keywords	2,042
Web of Science	("cognitive load" OR "cognitive load theory" OR “mental effort” OR “mental load” OR “human channel capacity” OR “mental workload”) AND (educat* OR education OR training OR trainee* OR student* OR learner*) in TOPIC	1,965
IEEE Xplore Digital Library	"cognitive load" OR "cognitive load theory"	28
Total records		7,263
Duplicated records		3,690
Total records de-duplicated		**3,573**

Although there are a larger number of references to review than with our initial search strategy, we believe the number is manageable and hopefully will produce more relevant studies.

Our planned Google Scholar search was added after the above scoping searches. As per section 4, we used similar search terms to the other searches planned.

9. Translation into practice

We anticipate that the studies retrieved and synthesized will yield practical benefits in two specific areas. First, our findings and synthesis may address a number of debated issues regarding CLT as a theory (see background section). Second, our compilation, summary and synthesis of included studies will provide a compendium of studies for educational researchers and practitioners to access, and also a set of "best practices" and recommendations for using CLT in workplace teaching, curriculum design, and educational research.

10. Project timetable

- Protocol development, review, and revision: Jul 2015-Mar 2016
- Database search: Apr 2015
- Study coding: May 2015-Jun 2016
- Data analysis and synthesis: Jul-Aug 2016
- Manuscript preparation and submission: Sept-Nov 2016

11. Conflict of interest statement

No author has any academic, institutional, political, personal, or other conflicts of interest to report. We do note that UCSF is a BEME BICC.

12. Plans for updating the review

After initial drafting of the manuscript, we will perform a repeat literature search (dates between date of initial literature search and date of repeat search) to identify any relevant studies published in the interim. Any relevant studies will be integrated into the review.

13. Changes to the protocol

Any changes to the protocol will be recorded. If these are significant, approval will first be sought from BEME.

14. References

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