Measuring cognitive engagement through interactive, constructive, active and passive learning activities.

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Abstract - **Among previous work on the benefits of active learning and engagement strategies when implemented in engineering learning environments, Chi's interactive, constructive, active and passive (ICAP) framework provided a way of categorizing learning activities. ICAP hypothesizes students' cognitive processing increases as they engage in active learning activities. The ICAP framework focuses on observable overt learning activities instructors can implement within their classrooms to increase student engagement and deep learning. With interactive activities being the most desirous of the four, Chi characterizes the various ways in which classroom activities span the passive to interactive continuum. The ICAP framework describes cognitive processing as being at its highest when students engage in meaningful dialogue about the topic with their peers and/or instructor. However, while Chi and colleagues operationalized each construct of the framework and subsequent theories of the level of student engagement, there is a lack in the development of instruments that can measure the level of cognitive engagement associated with these constructs. Consequently, this study is aimed at operationalizing the construct of cognitive engagement. This is the first phase in our attempt to develop an instrument that can be used to measure the cognitive processes associated with each construct of the ICAP framework.**

Index Terms – active learning, ICAP framework, instrument development, measuring cognitive engagement

INTRODUCTION

In 2009, Michelene Chi published her comparative literature review of how to differentiate active, constructive and interactive learning activities based on their educational benefits and the level of cognitive processing students experience when they produce overt observable outputs contingent upon the engagement [1]. The interactive-constructive-active-passive (ICAP) framework was developed to test the hypothesis that interactive activities are more beneficial to student learning than constructive activities which are more beneficial than active activities which are in turn more beneficial than passive activities (I>C>A>P). Differentiating these constructs, Chi discusses, is necessary for designing learning environments as well as assessing which learning activity is most effective in mediating student learning.

Passive learning is defined as the state in which students are receptors of knowledge without having any engagement or interaction in the process of their own learning. For example, if students just watch a video related to the content being taught and never engage in any other observable manner it is concluded that students are in a passive state. On the contrary, being active entails having students doing something physically such as writing notes from the board during a lecture. The cognitive process associated with the active construct includes activating existing knowledge in which the student is consciously searching through their existing knowledge in order to make some relation to the new information being presented. Being constructive, on the other hand, students are expected to produce outputs containing contextually-related ideas that build upon the information they have been given. Through constructive activities, students are able to infer meaning based on information presented and their own existing knowledge and interpretation to learn new idea. At this level, students' individual knowledge becomes richer and more coherent. When students are engaged interactively they collaborate with a peer and/or instructor to complete cognitive or physical tasks. However, based on Chi's definition, two students working on the same task is not considered interactive unless these students are critiquing and contributing their knowledge in a meaningful way. It is when students engage interactively that their cognitive processing is at its highest capacity. Through interactive dialogue students evaluate each other's knowledge to develop new ideas that incorporates their partner's critiques and collaborations [1], [2].

The operationalization of the four constructs previously defined: passive, active, constructive and interactive are dependent on the manifestation of directly observable/overt behaviors, or the lack of these behaviors, when students perform tasks associated with the given learning activity. Overt activities imply:

- it can be observed,
- it can be elicited or manipulated by instructor,
- it can be assessed in terms of frequency of occurrences,
- it can be coded and analyzed as evidence of mediators in learning [2].

However, the theorized cognitive processing associated with each construct cannot be fully assessed through observable means or overt activities. Consequently, research on how the cognitive processes associated with each construct in the ICAP framework can be measured is necessary. The overall goal of our study is to create an instrument that assesses students' cognitive processing when they engage in activities aligned with each category of the ICAP framework. The authors contend that cognitive processing in each category of the ICAP hierarchy is not linear. Meaning, a student could be overtly passive while experiencing high levels of cognitive processing. As part of a larger project aimed at developing an instrument for measuring students' cognitive engagement during in- and out-of-class activities, this paper focuses on the process of defining the construct of cognitive engagement. Cognitive engagement is classified as a latent construct, meaning it cannot be measured using observable scales [3], [4]. Instead, a latent construct such as cognitive engagement can be assessed by their effects [5]. Additionally, tangible scales that can be used to measure students' level of cognitive engagement when they participate in different learning activities along the passive to interactive continuum will also be explored.

METHODOLOGY AND METHODS

We used the work of DeVellis [3] and McCoach, Gable and Madura [4] on how to measure latent constructs as guiding principles. These authors suggest although latent constructs cannot be measured directly, "they do have a causal relationship with observed measures" [4, p. 35] which can be used to identify the latent construct. With this in mind, the researchers first utilized two pilot studies, each having its own research approach, to investigate how students engage in in- and out-of-class activities in order to later explore how measure cognitive engagement. Following the results of the first pilot study, an exploration of literature was conducted as part of the iterative process of construct operationalization.

I. Pilot study of in-class activities

A survey instrument was developed based on the constructs as operationalized by Chi and colleagues through an iterative process of item development. These items were meant to gauge students' perceptions of in-class activities and how they engage cognitively to solve problems. In this study, activities were defined as any external behavior and/or the relevant internal processes associated with completing a given task that could be considered as a mediator for learning. This instrument focused primarily on the types of learning activities students typically engage in such as taking notes, solving homework problems, asking questions in class, answering questions posed by instructor or peer and completing a given task with a peer. Items were written through an iterative process that included researchers in collaboration with content experts as well as conducting cognitive interviews with undergraduate students. At all times every effort was made to ensure that each item aligned with the constructs of the ICAP framework. Items were written to reflect only one construct at any given time, however the researchers acknowledged that the items were not exhaustive of all possible activities that would align with the ICAP framework constructs. The instrument was then piloted with 1363 students in various Science, Technology, Engineering and Mathematics (STEM) disciplines at a Pacific Northwest institution. using Qualtrics by STEM instructors emailing their students and inviting them to participate in the study. Table I shows an example of questions from the piloted instrument associated with each ICAP construct.

TABLE I
SAMPLE QUESTINS FROM PILOTED INSTRUMENT

ICAP Constructs	Sample Questions from Instrument
Interactive	In [COURSE NAME], how frequently do you create diagrams with others to help you understand the course material during class?
	In [COURSE NAME], how frequently do you provide evidence for your idea to a classmate(s) during class?
Constructive	When you are given time to solve problems during class how frequently do you work by yourself to better understand course material?
	In [COURSE NAME], how frequently do you take notes in your own words during class?
Active	In [COURSE NAME], how frequently do you take notes verbatim (word-for-word) during class?
	When you are given time to solve problems during class how frequently do you use a process that you are very familiar with to solve these problems?
Passive	In [COURSE NAME], how frequently do you just listen without doing anything else (even note taking) during class?
	When you are given time to solve problems during class how frequently do you wait for the answer from [EDUCATOR'S NAME] or a classmate without attempting the problem yourself?

II. Pilot study of students' out-of-class activities

Owning to the fact the ICAP framework was developed to capture in-class engagement, the researchers sought to investigate students' out-of-class engagement using the ICAP framework as a guide. Eight volunteer students were recruited to participate in weekly interview sessions across various graduate and undergraduate level STEM courses at the same Pacific Northwest institution. A semi-structured interview protocol was developed for these interviews that aligned with the ICAP framework. These interviews were meant to allow participants to recall their previous week to the best of their ability. The protocol encouraged participants to speak freely, as if they were conversing with a friend about their week, by asking broad open-ended questions followed by probing questions. This allowed for participants to delve deeper in explaining their out-of-class engagement and gave researchers the opportunity to ask follow up questions in case the participants lost focus. Each participant was given an introduction of the study and an explanation of the interview structure. The study followed participants from the beginning of their ten-week course through the final exam. This provided the opportunity for participants to discuss their out-of-class engagement with the researchers on a regular basis. The researchers were responsible for guiding the interviews through probing, a technique that uses questions in order to delve deeper into a topic, specifically the out-of-class engagement experienced. Many of the probing questions asked by the researchers were based on the content that the participant had brought up during the interview. Examples of a probing question used during an interviews were:

a. You mentioned working with a partner on this assignment; could you walk me through that interaction?
b. Could you describe how you engaged in that activity?
c. Were you just using prior knowledge or did you have to think really hard first?
d. When you completed the task were you just "going through the motions" or were you making an intentional effort to engage with what you were doing?

III. Continued operationalization of cognitive engagement

The results from the piloted instrument to asses in-class activities indicated that the previously developed items were measuring "frequency of occurrence" of activities and how frequently students engage in these activities. However, the intent of our project is to unearth the underlying mental processes associated with engaging in these activities. Consequently, using Chi and Wylie's discussion on cognitive load theory [2] as a spring board, the cognitive psychology literature was searched extensively starting with the similarity in results between the ICAP framework and cognitive load theory. In this phase of the study we sought to rigorously develop a definition for cognitive engagement based on the hypothesis of the ICAP framework. Chi hypothesizes that cognitive processing is increased as activities progress from passive to interactive. For example, ICAP predicts increasing engagement when students generate their own explanations of concepts (e.g. being constructive). This increase in engagement aligns with the premise of cognitive load which suggests when students explain their understanding of a concept the cognitive load associated with comprehension and processing of content (germane cognitive load) increase.

However, we contend that cognitive processing levels are not directly proportional with activity type. Additionally, we posit that different students will experience cognitive engagement and cognitive processing of class material differently. For example, while an activity might cause one student to be highly engaged the same activity could cause disinterest in another student. In order to investigate these postulations, we conducted an extensive literature search guided by the following questions:

a. What does being cognitive engaged look like?
b. What terms can we use to capture cognitive processing?
c. How is cognitive processing influenced by cognitive load?
d. What are alternative terms for cognitive processing?
e. How does the level of difficulty associated with an activity or task impact cognitive processing?

OPERATIONALIZING COGNITIVE ENGAGEMENT

In this section we present the initial analysis from the two pilot studies and results of the literature exploration. The concepts discussed are still being investigated and reframed consequently discussions in this section are preliminary.

I. Piloted instrument of in-class activities

Initial analysis using correlation matrices indicate strong correlations (0.6 and above) within and across items written to represent each of the four constructs. The strongest inter-item correlations were among interactive and constructive items (0.917) and interactive and active items (0.889). There were inter-item correlations between constructive, active and passive items however the value was relatively low. Consequently, further in-depth analyses such as factor and item analysis are necessary before generalized claims about the ability of these items to demonstrate patterns within the sample can be made. Additionally, the items on the instrument were written to gauge the frequency with which students engage in classroom activities that spanned the passive to interactive continuum. While frequency of occurrence is one of the main posits of the ICAP framework, the goal of our instrument is to measure students' level of cognitive engagement when they participate, whether passively, actively, constructively or interactively, in these learning activities.

II. Pilot study of out-of-class activities

The researchers have currently conducted forty-eight interviews across the 2015-2016 school year. From these interviews, various emerging trends have been noted to pursue when the remaining interviews are analyzed. Many of these emerging trends stem from how the participants are completing assignments (course projects and homework) and how the participants study for exams. The variety of documented engagements following the ICAP framework are far more wide-ranging when one type of activity (i.e. completing a weekly homework assignment) is compared across participants than when different activities are compared across a single participant. Another emerging theme from the data is the difference in levels of engagement within peer-to-peer interactions, which varies due to the context, environment, and participants taking part in the interaction. In addition to the themes that emerged, there may be others which this study will consider once all the data have been collected analyzed.

III. *Exploration of literature*

Using the literature, we have identified an iterative relationship between cognitive load, task complexity and mental/cognitive exertion that can be used to explore the measurement of cognitive engagement. Figure 1 illustrates the connection between these three concepts.

Cognitive Load

Cognitive load defined as a multi-dimensional concept incorporating *mental effort* (imposed by instructional parameters synonymous with *task complexity*) and *mental load* (amount of mental capacity that is allocated to instructional demands synonymous with *mental exertion*) [6]–[8]. There are three main types of cognitive load:

1. *Intrinsic*: complexity is dependent on difficulty level of item or component interactivity and the material being covered, i.e. how much information does the user have to hold in their working memory at any given period of time?
2. *Extraneous*: complexity is imposed by the format in which the material is presented and the requirements of the working memory necessary to make conceptual connections,
3. *Germane*: complexity is related to effort required of learner to process and comprehend material.

Cognitive load is therefore the summation of the three: intrinsic, extraneous and germane loads. However extraneous and germane can be manipulated by the design of instruction and learning material. "The same learning material can induce different amounts of memory load when different instructional strategies and designs are used for its presentation, because the different cognitive tasks required by these strategies and designs are likely to result in varying amounts of extraneous and germane load" [9, p. 55].

As a research construct cognitive load cannot be observed directly, instead its effects on internal cognitive processing of information can be self-reported by gauging investing mental effort or by using physiological, behavioral or learning outcome measures [8], [10]–[12]. Cognitive load encompasses other theoretical or latent constructs such as task complexity and mental/cognitive exertion, which are discussed in the following sections.

Task Complexity

In cognitive psychology, task complexity is discussed as significant in its impact on human performance and behavior. One school of thought supports the idea that performance of a task is dependent on the interaction of complexity and urgency, knowledge and skill, and nature of the environment [7]. In some instances, task complexity is described as a mediator of goal setting [6]. As this relates to cognitive engagement, task complexity can be characterized as the decision made on how much to engage in a task based on level of complexity. For example, as level of complexity increases students could be influenced to disengage. Along the lines of a latent construct, task complexity is defined as "a construct that explains how task characteristics impact the cognitive demands placed upon task performers" [7, p. 556].
Tasks are theorized to have three key components: products, required acts and information cues [6], [7], [13].

a. Products are defined as the required manifestations used to describe behaviors that can be measured. For example, when students take notes in class do they just write the notes as they are written on the board

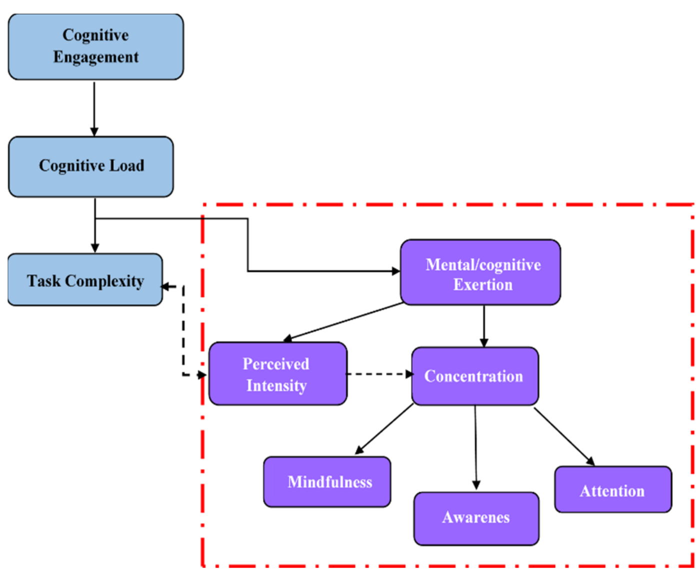

FIGURE 1
ILLUSTRATION OF THE RELATIONSHIP BETWEEN COGNITIVE ENGAGEMENT, COGNITIVE LOAD, TASK COMPLEXITY AND MENTAL/COGNITIVE EXERTION

(active) or do they make notes in their words (constructive) or do they discuss their ideas about the content with a peer or seek clarification from instructor then make notes (interactive).

b. Required acts are defined as the pattern of behavior that can be ascribed to a given purpose. These required acts would be the types of learning activities students are encouraged to participate in any of the four attributes of the ICAP framework.
c. Information cues are described as the pieces of information about the task itself and the subsequent judgment of level of cognitive processing required to be able to perform given tasks.

The subjective relationship between these three components can have significant influence on the performance of a given task but most importantly the level of cognitive processing and engagement.

Mental exertion

The concept of mental exertion is another latent or subjective construct that can only be measured by investigating its effects. A common approach to measuring exertion is by a concept known as linear or magnitude estimation [14]–[16]. This involves estimating the value of a given stimuli based on their perceived exertion. Using magnitude estimation, the number assigned to perceived intensity vary in direct proportion to an increase in intensity. The most common scale designed using magnitude estimation to measure physical exertion is Borg's ratio scaling of perceived exertion (RPE) [15]. The limitation to this approach however, is that the value assigned will be subjected to the participant's perception. For example, one person's maximum exertion is only applicable to them and not necessarily generalizable.

Concentration

The mental exertion literature brought to the surface the construct of concentration. Work on cognitive processing speaks to the influence of attention and concentration on learning in that information processing is dependent on the state of mind [12]–[14]. The principle of flow theory highlights the relationship between a particular challenge and the perceived skills necessary to meet said challenge. In relating this theory to student engagement, Shernoff et al. [20] posit "deep concentration in an activity has been shown to promote optimal learning experiences" (p. 161). However, flow theory suggests that at the heart of student engagement in classroom activities is the simultaneous interaction of the following variables:

1. concerted effort (challenge, skills and concentration)
2. intrinsic motivation (enjoyment, choice and interest)
3. importance

The influence of these concepts: cognitive load, task complexity, mental exertion and concentration, on cognitive engagement is very important to explore as we move forward into the next phase of instrument development.

Discussion

The ICAP framework was developed to categorize overt observable learning activities however, we are more interested in student self-report of the cognitive processing and engagement. Using the differences in the types of learning activities identified by Chi our goal is to develop an instrument that measures the presence of these constructs in learning environments and their effect on students learning. A second focus of our instrument is to assess students out-of-class engagement with class material in an attempt to capture cognitive and behavioral engagement in different learning environments. Therefore, it is necessary to develop instrument items that align with the posits of the ICAP framework while capturing what it means to be cognitively engaged. In addition, given Chi's caution that activities of a similar nature have to be measured against each other before they can be claimed as more beneficial, it is necessary to ensure that items written compare the same activity for all ICAP constructs. For example, an item written to assess cognitive engagement when taking notes should be written to compare passive, active, constructive and interactive note-taking.

Aligning our work with the ICAP framework has highlighted the fact that the hypothesis of the ICAP, as it relates to cognitive processing, is not measurable using only the types of learning activities identified by the framework. ICAP is more applicable to the observable effects of the learning activities and not necessarily all the internal processes necessary to elicit the desired response. To this end we are exploring cognitive psychology concepts as a starting point for the next phase of the study.

One significant implication of task complexity and mental/cognitive exertion when implementing the ICAP framework learning activities is the division of resources. Meaning, if students are required to perform two separate tasks, requiring the same cognitive resources, simultaneously e.g. generate new ideas about course content while interacting with a peer, these resources will be shared between tasks. Consequently, students' level of cognitive engagement will not be at its optimum level when this situation arises. Using the second pilot study and its goal of uncovering what activities students engage in outside of the classroom cognitively and socially, we are also exploring students frame of mind. We are particularly interested in their own thought processes while completing activities and how they incorporate interactive input from colleagues, when sought.

Additionally, we are also documenting our instrument design process. One author attends all research group meetings and takes extensive notes of the process by which new ideas have emerged. Having a design narrative provides the opportunity for the instrument developers to be able to identify the process whereby items were developed and how the collective decisions made were influenced by individual input. Documenting these processes creates transparency and overall face validity of the constructs the instrument will be measuring.

FUTURE WORK

Having explored the other latent constructs such as task complexity, concentration and mental/cognitive exertion with direct relation to cognitive engagement, the next step in our study is to use an adaptation of the following questions based on flow theory in student focus groups to develop a scale. This scale will be designed to measure students' frame of mind when completing or participating in a given task. The questions supported by flow theory are:

a. How important is the activity?
b. Do you have a choice in completing the activity?
c. What is your level of interest? Enjoyment?
d. How hard are you concentrating?
e. What skills/knowledge are you using when completing a given task?
f. Do you wish you were doing something else? [21, p. 124].

Using the collective results of the second pilot study and student focus groups new items will be written. This new instrument will be piloted and revised as necessary.

The overall results of this study will have significant implications for the design of learning environments and the types of activities instructors create for students. Students' level of cognitive engagement when completing course activities can have significant influence of how well they learn that material being taught.

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