STRUCTURAL EQUATION MODELLING OF COGNITIVE LOADING IN THE CDIO PEDAGOGICAL APPROACH

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ABSTRACT
CDIO programs have tenets of self-directed learning and often use either problem or project based learning. The assessment questions usually model real world engineering scenarios using fairly complex questions which are located in the 'zone of proximal development' (ZPD) of the students. The efficacy of the CDIO approach is reported in many studies and the approach is emerging as an accepted best practice in the field of engineering education. However, the consequence of the CDIO pedagogical approach on the cognitive load induced in students is not understood. This study therefore aimed to ascertain the amount of cognitive load induced due to the central tenets of the CDIO approach namely, complex questions, zone of proximal development and self-directed learning. The study follows a quantitative research design and a positivist philosophy using a deductive research approach using a cross sectional questionnaire survey and non-probability sampling. Structural equation modelling was performed using IBM SPSS AMOS v25 while descriptive and reliability analysis were done using SPSS v25. The findings show that the use of complex questions yields significant levels of cognitive load and locating the questions in the zone of proximal development of students also induces some amount of cognitive load. Self-directed learning on the other hand does not subject students to significant levels of cognitive load. Several studies have established the detrimental impact of high levels of cognitive loading on learning. The findings therefore suggest that it is necessary and important to monitor and manage the levels of cognitive loading induced by the CDIO approach so that it does not begin to interfere with the learning process. Specifically, the complexity of the assessment problems used should be carefully planned to be appropriate to the knowledge level of the students and not located outside the zone of proximal development of the students.

KEYWORDS
Structural Equation Modelling, Cognitive Loading, Complex Questions, Zone of Proximal Development, Self-Directed Learning.

INTRODUCTION
The CDIO (Conceiving-Designing-Implementing-Operating) pedagogical approach which models real world products, processes and systems while teaching engineering education is becoming an accepted best practice in engineering education (CDIO, 2017). It is an innovative educational system characterized by a cycle modelled on the real world engineering practice of delivering engineering solutions firstly by being able to conceive the engineering solution by defining customer needs and considering all relevant aspects incidental to the conception of the solution; secondly by being able to design the appropriate solution and thirdly by being able to implement the design by transforming it into a product and finally being able to operate the product to achieve the intended value (CDIO, 2004). It is mainly delivered through a student

centred approach hinged on active learning with an integrated curriculum delivered through problem based learning (Ibid). Students are encouraged to engage in the practice of engineering through problem solving and design exercises.

The CDIO approach offers many advantages to engineering education. Zeng, Juanping & Wang (2015) reported improved student project ability while Rouvrais & Landrac (2012) reported improved program quality and ability to meet accreditation standards at Telecom Bretagne, Institut Mines-Telecom; Université européenne de Bretagne in France after they chose to use CDIO standards for improvement. Telecom Bretagne uses an integrated curriculum focused on developing competences and personal and professional skills. This is achieved through a student centered approach delivered through project based learning (Project-BL) and an active pedagogy. The projects are linked to complex pluridisciplinary system (Rouvrais & Landrac, 2012).

The student centered approach with active learning implicit in the CDIO programs encourages students to engage in self-directed learning. This makes the CDIO approach very relevant to the current circumstances where there is an explosion of knowledge due to advances in technology. Modelling the assessment projects on real world scenarios which are complex and multi-disciplinary often makes the questions complex. Questions may be classified as complex when their answers need to be collated from information scattered in many different documents (Chali, Hasan and Mojahid, 2015) or from different bodies of knowledge in different disciplines.

Effectively, complex questions in a real world situation locate the learning tasks of the CDIO programs in the Zone of Proximal Development (ZPD) of the students. This is ideal for learning and is supported by several research findings. However, based on the cognitive load theory, complex learning tasks located in the ZPD are likely to overload the working memory limits and induce relatively high levels of cognitive load.

The relationship between complex questions and cognitive loading has been widely researched and it is accepted that complex questions induce high levels of cognitive load. However, the relationships among ZPD, SDL and cognitive loading are hardly understood especially when considered in relation to complex questions. Therefore, this study investigates the relationships among the four constructs of Complex Questions, ZPD, SDL and Cognitive Loading to ascertain the amount of cognitive load induced by each of the three aspects of a CDIO program. The relationships among the four constructs have implications for the CDIO approach since the approach strongly exhibits aspects of ZPD, SDL and uses fairly complex questions in a real world setting. These aspects of the CDIO approach make it predisposed to inducing relatively large amounts of cognitive loading in students.

LITERATURE REVIEW

Cognitive Loading

Cognitive loading is the mental load on working memory expended in executing cognitive functions such as perceiving, thinking and learning among others. Because working memory has a very limited capacity, it tends to get overloaded and overwhelmed when its limits are stretched. Instructional approaches which induce lower levels of cognitive load result in better learning outcomes for students while those which ignore the limits of working memory often inhibit learning (Kirshner, 2002; Van Gerven et al., 1994; Tasir & Pim, 1994). Therefore, lower levels of cognitive loading induced in students will work to yield more effective learning than when the memory limits of students are ignored and the cognitive load is left to exceed the memory limit. This is based on the cognitive load theory (CLT) which posits that since working memory has a very limited capacity, it can be easily overloaded with activities that impede rather than aid learning and subsequently, effective learning happens when the cognitive load in working memory is directed towards construction and automation of relevant schemata (Sweller, 2002; Pollock et al., 2002; Sweller et al., 1998). Scheiter et al., (2009) found that students with lower levels of cognitive load exhibited better problem-solving performance.

Cognitive loading is an important consideration in educational practice since learning will hardly take place if the limits of working memory are ignored (Sweller et al., 1998; Van Gerven et al., 2002). Pedagogies which ignore cognitive loading are unlikely to achieve maximum efficiency in learning since the working memory capacity of students is likely to be exceeded (Bannert, 2002; Sweller, G., van Merrienboer, & Paas, 1998).

Zone of Proximal Development

The Zone of Proximal Development (ZPD) is 'the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers' (Vygotsky, 1978: 86 cited in Berkiryazicic, 2015). Learning consist of challenging students to perform tasks located in the ZPD and providing assistance in performing the task until the students are able to perform the task on their own and subsequently the students continually increase the range of tasks they can perform on their own (Naeini, 2014; Shooshtari & Mir, 2014).

Challenging students with tasks in the ZPD ensures that students are cognitively challenged to broaden the range of tasks they can confidently perform without supervision. The change in the range of tasks which students can perform quintessentially defines cognitive development and so learning.

Self-Directed Learning

Self-directed learning (SDL) is a strong predictor of and enhances academic performance and learning (Alharbi, 2017; Alotaibi, 2016; Lee, Yeung, & Ip, 2017) and can improve quality of life (Din, Haron, & Rashid, 2016). Its importance has been argued in many studies (Alharbi, 2017; Alotaibi, 2016; Din et al., 2016; Lee et al., 2017; Louws, Meirink, van Veen, & van Driel, 2017; Nasri, 2017; Rashid & Asghar, 2016; Slater & Cusick, 2017; Zhoc & Chen, 2016). SDL is becoming increasingly important in the current era of knowledge explosion. The knowledge explosion being experienced due to rapid developments in technology and information and telecommunications is placing a huge burden on both lecturers and students to stay abreast the huge volume of knowledge and its application being constantly generated (Alotaibi, 2016; Zhoc & Chen, 2016). Consequently, it is becoming increasingly difficult for lecturers to teach all the disciplinary knowledge to students and for students to learn in class. Subsequently, SDL is becoming a critical avenue through which the gap between what can be taught and learnt in class and what ultimately needs to be learnt can be bridged (Alotaibi, 2016).

Self-directed learning (SDL) refers to the ability for students to engage in independent learning activities without any explicit direction from anyone (Alharbi, 2017; Din et al., 2016). It involves students identifying their own learning needs including identifying learning needs, setting learning goals, identifying appropriate learning resources, choosing and applying appropriate learning strategies and evaluating learning outcomes (Alharbi, 2017; Din et al., 2016).

Cognitive Loading in Minimally Guided Pedagogies

Kirschner, Sweller, and Clark (2006) classified problem and project based learning approaches (which is favored in CDIO programs) as minimally guided pedagogical approaches and argued that they are less effective than instructional approaches which are more strongly guided. Kirschner, Sweller, and Clark (2006: 75) argued that minimally guided approaches:

> "ignore both the structures that constitute human cognitive architecture and evidence from empirical studies over the past half-century that consistently indicate that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process. The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide 'internal' guidance."

Fundamentally, Kirshner, Sweller, and Clark argue against the use of problem or project based learning in students with little prior subject knowledge due to the resulting levels of cognitive loading. Proponents of the CLT argue against instructional approaches which require some level of complex reasoning from students in the absence of adequate subject prior knowledge which is often the case in problem and project based learning (Amadieu, van Gog, Paas, Tricot, & Mariné, 2009; Ayres, 2006; Kirschner, 2002; Paas & van Gog, 2006). Problem or project based learning is one of the central tenets of the CDIO approach throughout the program. Therefore, Kirshner et al. and others essentially argue against the use of the CDIO approach until students have acquired sufficient subject prior knowledge. The argument by Kirshner, Sweller, and Clark and others led to the research hypotheses and conceptual framework.

HYPOTHESIS DEVELOPMENT AND CONCEPTUAL FRAMEWORK

Complex questions and Cognitive loading

The use of complex questions modelling real world problems implicit in the CDIO approach when students have not yet mastered the subject knowledge makes CDIO predisposed to relatively high levels of cognitive loading. This conception supported by findings from other studies led to the first research hypothesis which can be stated as:

H_1: There is a positive relationship between complex questions (CQue) and cognitive loading (CgLd)

ZPD and Cognitive loading

Assessment tasks located in the ZPD of students will also induce cognitive loading but much less than that induced by complex questions. This is because tasks which are located in the ZPD can be resolved with help from a more experienced person while complex tasks may in fact be located outside the ZPD. Therefore, the second research hypothesis can be stated as:

H_2: There is a positive relationship between ZPD and cognitive loading (CgLd)

SDL and Cognitive loading

SDL is not expected to induce cognitive loading since the pace and amount of work engaged in through SDL is controlled by the student. Therefore, it is unlikely that the cognitive load would exceed the limits of the students since cognitive load induces stress and students will naturally

limit the amount of stress they will expose themselves to voluntarily. This conception led to the third hypothesis which can be sated as:
H_3: There is no statistically significant relationship between SDL and cognitive loading (CgLd)

Complex questions and ZPD
Solving complex questions require the collation of information found in different sources and often from different bodies of knowledge. This means that students often fail to solve the problems unless with guidance. Therefore, complex questions are located in the ZPD of student. This led to the hypothesis that:
H_4: There is a positive relationship between complex questions (CQue) and the ZPD.

SDL and ZPD
Learning consists of students increasing the range of tasks which they can perform without guidance from a more knowledgeable person. Essentially, it consists of converting some of the ZPD into what can be done without help. Therefore, even when students engage in SDL, rather than attempt to solve problems which they can handle on their own, they work on problems which are in the ZPD. This led to the hypothesis that:
H_5: There is a positive relationship between SDL and ZPD.

SDL and Complex questions
When engaging in SDL, students are expected to attempt questions located in the ZPD. Considering that complex questions are expected to be located in the ZPD, it should also be expected that SDL will lead students to attempt complex questions. Therefore, it may be hypothesized that:
H_6: That there is a positive relationship between SDL and complex questions (CQue)

Following from the proposed hypotheses, the proposed conceptual model can be presented as follows:

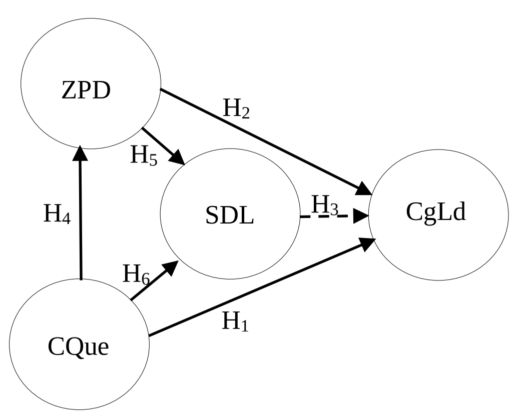

Figure 1: Conceptual Model

METHODOLOGY
Research design
A quantitative research design with a positivist philosophy and a deductive research approach were used because the study sought to test hypothesized relationships among the study variables

to which the quantitative design, a positivist philosophy and a deductive approach are all well suited. The favored data collection method was a cross sectional questionnaire survey due to the objectivity and low cost associated with its use compared to other methods of data collection. Non probability sampling was used for convenience and economy.

Operationalization

The scales in the questionnaire were developed based on the operational definition of the study constructs. Cognitive loading was operationalized mainly as the extent to which students are overwhelmed by the amount of assigned work and the extent to which they are expected to remember too much information which was complex, difficult and confusing to understand. This conception is shared by others (Çolak & Kaya, 2014; Hadie and Yusoff, 2016) and is also supported by the findings which show that high levels of cognitive loading lead to students being overwhelmed (Scheiter et al., 2009; Çolak & Kaya, 2014). The concept of complex questions was operationalized by extent to which students were given assessment problems which were difficult to understand, hand no defined solution and required combining information from different subject areas and sources. Zone of proximal development (ZPD) was operationalized as the extent to which students were presented with problems which were beyond what they could comfortably solve without further guidance. Self-directed learning was operationalized by the extent to which the students were expected to engage in learning activities on their own and without further guidance.

The questionnaire, along with the entire study, were reviewed by the university research ethics committee and approved. The instrument was anchored on a 5 point Likert scale with 5=almost never; 4=often; 3=sometimes; 2=seldom; and 1=almost never.

Data collection procedure

The target population for the study were students undertaking construction studies at public universities in South Africa. Three public universities in the KwaZulu-Natal province were conveniently selected for the study. All students present in class at the time of the data collection were included in the sample. The questionnaires were circulated to students at the start of lectures. Arrangements were made with respective lecturers responsible for different classes to allow 30 minutes at the start of their lectures to administer the questionnaires. Students were requested to fill in the questionnaire after explaining to them the details of the study and the instructions for filling in the form. The students were informed of their right to not participate in the study and to withdraw at any time for any reason. The students were also assured of both confidentiality and anonymity if they chose to participate. The students were not informed beforehand that a questionnaire would be circulated and so attendance was not influenced by the study. Therefore, absconding students were purely random and it can be concluded that the available sample of students was representative of the population of interest. A sample of 273 students studying towards bachelor’s degrees in either Construction Management, Quantity Surveying or Property Studies at three public universities in the province of KwaZulu-Natal, in South Africa was obtained.

RESULTS

Table I shows the profile of the respondents. The table shows that more than half of the students are either in the third or fourth year of study indicating that the majority of the respondents have sufficient experience and knowledge about the university experience. While second year students account for a small percentage of the respondents, they are equally sufficiently experienced and knowledgeable about the university experience. First year students on the other hand, who account for less than a third of the respondents, are also fairly knowledgeable about the university experience since the data were collected towards the end of the academic year.

Table I. Sample Demographic Statistics

Year of Study	**Frequency**	**Percentage**
1	71	26.0%
2	30	11.0%
3	61	22.3%
4	111	40.7%
Total	**273**	**100%**
Gender	**Frequency**	**Percentage**
Male	158	57.9%
Female	115	42.1%
Total	**273**	**100%**
Program of Study	**Frequency**	**Percentage**
Construction Management	128	46.9%
Quantity Surveying	93	34.1%
Property Studies	52	19.1%
Total	**273**	**100%**

The gender distribution of the respondents is a very fair representation of the general gender distribution at the sampled universities. Most of the respondents were pursuing the construction management program with the program of property studies contributing less than a third of the respondents. Construction management and quantity surveying were offered at both the sampled universities while property studies was offered only at one of the universities which is why the number of respondents pursuing property studies is relatively lower.

Measurement Model Assessment

Prior to assessing the structural relationships among the constructs, the measurement model was first assessed for model fitness. This two-step approach was suggested by Anderson and Gerbing (1998). All the constructs were displayed as linked first order factors. In assessing the measurement model, AMOS 25 statistical software was used. Table II shows the results of the measurement model and also the reliability and validity statistics of the measurement instrument. Reliability was assessed using Cronbach’s alpha, item-to-total correlation and Composite Reliability (CR) while validity was assessed using Average Variance Extracted (AVE). For discriminant validity to exists, the square root of the AVE should be less than the shared variance (inter correlation) between the two constructs (Fornell and Larcker, 1981). Cronbach’s alpha for all constructs ranged between 0.731 and 0.899 which exceeded the recommendation of 0.70 by Byrne (2006). Item-to-total correlations ranged between 0.525 and 0.820 which exceeded the recommendation of 0.50. Hulland (1999) recommended a threshold of 0.60 for CR. However, two constructs had CR slightly less than the recommended 0.60 while the other two had CR values greater than 0.70. Therefore, overall, the study constructs had a marginally acceptable CR. Fornell and Larcker (1981) recommend AVE values to be greater than 0.50. However, two of the constructs had AVE values less than 0.50 while the other two had values greater than 0.50 indicating a marginally acceptable AVE for the constructs. Evidence of discriminant validity can be seen in Table III which shows the square root of the AVE in the diagonal and the inter-construct correlation in the remainder of the table.

Table II. Measurement Model Assessment

Research Constructs		Mean	Cronbach's Test		C.R.	AVE	Item Loadings
			Item-total	α Value			
CogLd1	I was overwhelmed with the amount of information I was expected to remember	3.254	0.587	0.837	0.614	0.468	0.501
CogLd2	I was given too much information during the lectures		0.666				0.645
CogLd3	The information I was given during lectures was confusing		0.606				0.820
CogLd4	The information I was given in class was complicated and difficult to understand		0.646				0.834
CogLd5	I was overwhelmed with the amount of work I had to do		0.611				0.553
CQue1	I was given assignments and tests which were difficult to understand and solve	2.924	0.641	0.899	0.792	0.605	0.679
CQue2	I was given problems which did not have enough information for me to solve them		0.791				0.859
CQue3	I was required to solve questions which were not clear as to what I was expected to do		0.820				0.878
CQue4	I was given questions which could be interpreted in more than one way		0.604				0.626
CQue5	I was given problems which were not easy to understand clearly		0.783				0.817
CQue6	I was given questions which were not expressed clearly		0.721				0.774
ZPD1	I found tests and assignments to be very challenging	3.275	0.511	0.731	0.513	0.393	0.513
ZPD2	I was given work which was beyond what I could manage to do on my own		0.538				0.634
ZPD3	I was given work which required further guidance from the lecturers in order to complete it		0.562				0.720
ZPD4	I was given work which required consulting with more knowledgeable people in order to do it well		0.473				0.624
SDL1	I was required to find additional knowledge and information on my own	3.917	0.660	0.808	0.717	0.544	0.800
SDL2	I was given work which required me to learn new concepts on my own		0.716				0.814
SDL3	I was expected to expand on what was taught in class on my own		0.681				0.777
SDL4	I was required to learn on my own		0.471				0.518

All the inter-construct correlations are less than the square root of the AVE indicating good discriminant validity. Further, all the inter-construct correlations are less than 0.80 suggesting that there is no multi-collinearity. The factor loadings ranged between 0.501 and 0.859 and so all the factor loadings meet the minimum threshold of 0.50 recommended by Anderson & Gerbing (1998).

Table III. Inter-construct Correlations and Discriminant Validity

	COMPQ	COGLD	ZPD	SDL
COMPQ	**0.778**			
COGLD	0.519**	**0.652**		
ZPD	0.296**	0.353**	**0.627**	
SDL	0.090	0.148*	0.247**	**0.738**

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

The measurement model was assessed for fitness with thresholds as suggested by Bentler (1990), Browne and Cudeck (1993) and Marsh et al. (1996). The measurement model fit indices are shown in Table IV. Two of the fit indices namely the NFI and the TLI fell outside the minimum acceptable threshold. However, this does not necessarily indicate an implausible fit of the primary data structure but perhaps a rather marginally acceptable model structure of the primary data. Therefore, the model was provisionally accepted since it had a moderately close fit to the observed data.

Table IV. Measurement Model Fit Summary

Model Fit Index	Acceptable Threshold	Study Threshold	Met/Not Met
Chi-Square value: X/df	<3	2.519	Met
Comparative Fit Index (CFI)	>0.900	0.900	Met
Incremental Fit Index (IFI)	>0.900	0.903	Met
Normed Fit Index (NFI)	>0.900	0.848	Not met
Tucker Lewis Index (TLI)	>0.900	0.867	Not met
Random Measures of Sample Error Approximation (RMSEA)	<0.080	0.075	Met

Results of the Structural Model

Since a fairly acceptable measurement model was found, the structural model fit was evaluated and the relationships among the study constructs assessed through path modelling. The structural model also showed a fairly acceptable fit with results shown in Table V. of the six fit indices checked, four met the minimum threshold of acceptance according to Bentler (1990), Browne & Cudeck (1993) and Marsh et al. (1996) while two failed to meet the minimum threshold requirements. For this reason, the model was assessed to moderately fit the primary data structure and the model was provisionally accepted.

Table V. Structural Model Fit Summary

Model Fit Index	Acceptable Threshold	Study Threshold	Met/Not Met
Chi-Square value: X/df	<3	2.508	Met
Comparative Fit Index (CFI)	>0.900	0.901	Met
Incremental Fit Index (IFI)	>0.900	0.903	Met
Normed Fit Index (NFI)	>0.900	0.848	Not met
Tucker Lewis Index (TLI)	>0.900	0.868	Not met
Random Measures of Sample Error Approximation (RMSEA)	<0.080	0.074	Met

Hypothesis Evaluation

Having checked the structural model for fitness with the primary data structure and accepted the model as being a fair representation of the data structure, the hypothesized structural relationships among the variables were tested. The results of the hypothesis testing are shown in Table VI.

Table VI. Hypothesis Evaluation

Proposed Hypothesis			Hypothesis	Factor Loading	Rejected/Supported
CQue	→	CgLd	$+H_1$	0.269**	Supported
ZPD	→	CgLd	$+H_2$	0.109**	Supported
SDL	→	CgLd	H_3	0.023	Supported
CQue	→	ZPD	$+H_4$	0.209**	Supported
ZPD	→	SDL	$+H_5$	0.098**	Supported
CQue	→	SDL	$+H_6$	0.209**	Supported

The first hypothesis postulated that there is a positive relationship between complex questions and cognitive loading. The results provide support for the hypothesis with a statistically significant relationship at 99% confidence interval between the two with complex questions contributing 26.9% of the explained variance on cognitive loading. The second hypothesis postulated that there is no statistically significant relationship between SDL and cognitive loading. While the results show an explained variance of 2.3% of cognitive loading from SDL, the association is not statistically significant and therefore the small explained variance shown is only a chance occurrence. The third hypothesis postulated that there is a positive relationship between ZPD and cognitive loading. The results support the hypothesis with a statistically significant relationship between the two variables with ZPD contributing 10.9% explained variance to cognitive loading. The fourth hypothesis postulated that there is a positive relationship between complex questions and the ZPD. The results support the hypothesis with a statistically significant relationship between the constructs with complex questions explaining 20.9% of the variance in ZPD. The fifth hypothesis postulated that there is a positive relationship between SDL and ZPD. The results support the hypothesis with SDL explaining 9.8% of variance in ZPD which is statistically significant. The sixth and last hypothesis postulated that there is a positive relationship between SDL and complex questions. The results support the hypothesis with a statistically significant relationship with complex questions explain 20.9% variance in SDL.

DISCUSSION

This study aimed at quantitatively establishing the amount of cognitive load induced by complex questions, ZPD and SDL which are the main tenets of a CDIO program. The study also sought to model the relationships among the four constructs. The study found that complex questions and ZPD induce statistically significant levels of cognitive loading with complex questions inducing more than twice the cognitive load induced by ZPD. SDL on the other hand does not induce statistically significant levels of cognitive loading. The results also show that complex questions are located in the ZPD and that complex questions and ZPD encourage SDL.

While complex questions are in fact located in the ZPD, they induce more cognitive loading than the ZPD research construct. This suggests that, since ZPD is a region, complex questions are actually located at the very outer edge of the region next to the region were students cannot solve problems even with help from a more knowledgeable person. Therefore, assessment problems which are located on the outer edge of the ZDP and are perceived as complex by students will induce fairly large amounts of cognitive loading.

Complex questions consistently lead to cognitive loading and SDL. Therefore, while inducing cognitive loading, complex questions also encourage SDL at the same time. The importance of SDL to academic performance and achievement has been reported in many studies (Alharbi, 2017; Alotaibi, 2016; Din et al., 2016; Lee et al., 2017; Louws, Meirink, van Veen, & van Driel, 2017; Nasri, 2017; Rashid & Asghar, 2016; Slater & Cusick, 2017; Zhoc & Chen, 2016). Conversely, cognitive loading has been reported to have negative consequence on learning (Kirshner, 2002; Van Gerven et al., 1994; Tasir & Pim, 1994; Amadieu et al., 2009; Ayres, 2006; Paas & van Gog, 2006). Therefore, on one hand, complex questions have an adverse impact on learning by inducing cognitive loading while on the other hand they have a beneficial effect in that they encourage SDL.

According to Vygotsky, learning happens when students are challenged to solve problems which are located in their ZPD with the help of a more knowledgeable person. Given that assessment problems located in the ZPD induce cognitive loading, some cognitive loading may be necessary for learning to happen. Considered in relation to theory on the ZPD by Vygotsky, it would appear that it may not be possible or even necessary to eliminate cognitive loading for learning to take place. However, high levels of cognitive loading certainly hinder learning.

CONCLUSION

Extant literature suggests that cognitive loading is detrimental to learning while SDL is beneficial. Therefore, complex questions play a partially opposing role of simultaneously enhancing and impeding learning by inducing cognitive loading on one hand and encouraging SDL on the other. Alternatively, it may be that learning cannot happen in the absence of some level of cognitive loading because all beneficial cognitive learning tasks require a level of cognitive deployment which will consequently induce some level of cognitive loading. This would explain the dual consequence of complex questions of simultaneously inducing cognitive load while encouraging SDL. The cognitive loading would be the consequence of cognitive effort required to handle problems which are in the ZPD. This conclusion is supported by the cognitive load theory and supported by empirical evidence that when students are subjected to problems about which they have little subject prior knowledge, they will experience high levels of cognitive loading. The SDL induced by complex questions can be explained by what the response of students to complex questions in the absence of sufficient help from a more knowledgeable person. Invariably, students will turn to SDL in order to handle the complex problem on their own which then also explains the cognitive loading induced by the complex questions. Therefore, if the questions are too complex and they induce too much cognitive loading while solving them, then learning will be impeded rather than enhanced.

CDIO programs should therefore consider the level of complexity of the assessment problem used in association with problem or project based learning. The fact that these pedagogies require students to engage in SDL means that the students are very likely going to experience fairly significant amounts of cognitive loading especially when the task is too complex. Further, appropriate support from knowledgeable persons is very important even as students engage in SDL to mitigate the effect of high cognitive load from complex tasks.

LIMITATIONS

While the findings of this study provide valuable insight into the relationships of complex questions, SDL, ZPD with cognitive loading and their implications for CDIO programs, the study has some limitations. Firstly, the proposed model only just moderately fits the data. Therefore, while the proposed model does suggest a reasonably plausible representation of the primary data structure, other structural models may better represent the primary data structure and yield better structural model fit. Therefore, future studies may propose other models and consider other variables which may affect the model so as to achieve a better model fit and so report the structural relationships more assertively. Secondly, this study used a sample from a non CDIO program to make inference about the likely consequence of the CDIO approach on the cognitive loading of students. Therefore, the findings presented here only provide anecdotal evidence of the possible consequence of CDIO approach on cognitive loading. Other factors in a CDIO program may in fact moderate the consequence of the studied variables and alter the structural relationships with cognitive load. For example, the extent of scaffolding applied in the CDIO program especially when students find the assessments too complex definitely moderates the structural relationships with cognitive loading. Therefore, besides expanding the model to include more relevant variables, future studies with a sample from a CDIO program will provide more valid and reliable findings that can inform CDIO programs.

REFERENCES

Alharbi, H. A. (2017). Readiness for Self-Directed Learning: How Bridging and Traditional nursing students differs? *Nurse Education Today*. doi: https://doi.org/10.1016/j.nedt.2017.12.002

Alotaibi, K. N. (2016). The learning environment as a mediating variable between self-directed learning readiness and academic performance of a sample of saudi nursing and medical emergency students. *Nurse Education Today, 36*, 249-254. doi: https://doi.org/10.1016/j.nedt.2015.11.003

Amadieu, F., van Gog, T., Paas, F., Tricot, A., & Mariné, C. (2009). Effects of prior knowledge and concept-map structure on disorientation, cognitive load, and learning. *Learning and Instruction, 19*(5), 376-386. doi: http://dx.doi.org/10.1016/j.learninstruc.2009.02.005

Anderson, J. C. & Gerbing, D. W. (1988). Structural Equation Modeling in Practice: A Review and Recommended Two-Step Approach, *Psychological Bulletin*, 103, 411–423

Ayres, P. (2006). Using subjective measures to detect variations of intrinsic cognitive load within problems. *Learning and Instruction, 16*(5), 389-400. doi: http://dx.doi.org/10.1016/j.learninstruc.2006.09.001

Bannert, M. (2002). Managing cognitive load—recent trends in cognitive load theory. *Learning and Instruction*, *12*(1), 139-146. doi: http://dx.doi.org/10.1016/S0959-4752(01)00021-4

Bekiryazici, M. (2015). Teaching Mixed-Level Classes with a Vygotskian Perspective. *Procedia - Social and Behavioral Sciences, 186*, 913-917. doi: https://doi.org/10.1016/j.sbspro.2015.04.163

Bentler, P. M. (1990). Comparative Fit Indexes in Structural Models, *Psychological Bulletin*, 107(2), 238-246

Browne, M. W. & Cudeck, R. (1993). Alternative Ways of Assessing Model Fit. In Bollen, K. A & Long, J. S. (eds.). Testing Structural Equation Models, 136–61. Newbury Park, CA: Sage Publications

Byrne, B. M. (2006). Structural Equation Modeling with EQS: Basic Concepts, Applications, and Programming (2nd ed.). Mahwah, NJ: Lawrence Erlbaum Associates

Chali, Y., Hasan, S. A., & Mojahid, M. (2015). A reinforcement learning formulation to the complex question answering problem. *Information Processing & Management*, *51*(3), 252-272. doi:https://doi.org/10.1016/j.ipm.2015.01.002

CDIO (2004). The CDIO™ Standards. PDF available at http://www.cdio.org/files/standards/cdio_standards_1.0.pdf, accessed on 23/01/2018

CDIO (2017). The CDIO™ initiative is an innovative educational framework for producing the next generation of engineers. URL available at http://www.cdio.org/about, accessed 23/01/2018

Çolak, E. & Kaya D. (2014). Learning Approaches of Vocational High School Students: Grade Level and School Type Influences. *Procedia - Social and Behavioral Sciences*, 2014. 116: p. 1556-1561.

Din, N., Haron, S., & Rashid, R. M. (2016). Can Self-directed Learning Environment Improve Quality of Life? *Procedia - Social and Behavioral Sciences, 222*, 219-227. doi: https://doi.org/10.1016/j.sbspro.2016.05.150

Fornell, C. & Larcker, D. F. (1981). Evaluating Structural Equation Models with Unobservable Variables and Measurement Error, *Journal of Marketing Research* 18 (1), 39-50

Hadie, S.N.H. & Yusoff, M.S.B. (2016). Assessing the validity of the cognitive load scale in a problem-based learning setting. *Journal of Taibah University Medical Sciences*, 11(3): p. 194-202.

Hulland, J. (1999). Use of Partial Least Squares (PLS) in Strategic Management Research: A Review of Four Recent Studies, *Strategic Management Journal*, 20(2), 195–204

Kirschner, P. A. (2002). Cognitive load theory: implications of cognitive load theory on the design of learning. *Learning and Instruction, 12*(1), 1-10. doi: http://dx.doi.org/10.1016/S0959-4752(01)00014-7

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist, 41*(2), 78-86. doi: 10.1207/s15326985ep4102_1

Kirschner, P.A., (2002). Cognitive load theory: implications of cognitive load theory on the design of learning. *Learning and Instruction*, 12(1): p. 1-10.

Lee, C., Yeung, A. S., & Ip, T. (2017). University english language learners' readiness to use computer technology for self-directed learning. *System, 67*, 99-110. doi: https://doi.org/10.1016/j.system.2017.05.001

Leppink, J., Paas, F., van Gog, T., van der Vleuten, C.P.M., & van Merriënboer, J.J.G. (2014). Effects of pairs of problems and examples on task performance and different types of cognitive load. *Learning and Instruction*, 30: p. 32-42.

Louws, M. L., Meirink, J. A., van Veen, K., & van Driel, J. H. (2017). Teachers' self-directed learning and teaching experience: What, how, and why teachers want to learn. *Teaching and Teacher Education*, *66*, 171-183. doi: https://doi.org/10.1016/j.tate.2017.04.004

Marsh, H. W., Balla, J. R. & Hau, K. T. (1996). An Evaluation of Incremental Fit Indices: A Clarification of Mathematical and Empirical Properties, In Marcoulides, G. A. & R. E. Schumacker (eds.). Advanced Structural Equation Modeling, *Issues and Techniques*. Mahwah, NJ: Lawrence Erlbaum Associates Publishers

Naeini, J. (2014). On the Study of DA and SLA: Feuerstein's MLE and EFL Learners' Reading Comprehension. *Procedia - Social and Behavioral Sciences, 98*, 1297-1306. doi: https://doi.org/10.1016/j.sbspro.2014.03.546

Nasri, N. M. (2017). Self-directed learning through the eyes of teacher educators. *Kasetsart Journal of Social Sciences*. doi: https://doi.org/10.1016/j.kjss.2017.08.006

Paas, F., & van Gog, T. (2006). Optimising worked example instruction: Different ways to increase germane cognitive load. *Learning and Instruction, 16*(2), 87-91. doi: http://dx.doi.org/10.1016/j.learninstruc.2006.02.004

Pollock, E., Chandler, P. & Sweller, J. (2002). Assimilating complex information. *Learning and Instruction*, 12(1): p. 61-86.

Rashid, T., & Asghar, H. M. (2016). Technology use, self-directed learning, student engagement and academic performance: Examining the interrelations. *Computers in Human Behavior, 63*, 604-612. doi: https://doi.org/10.1016/j.chb.2016.05.084

Rouvrais, S. & Landrac, G. (2012) Resistance to Change in Institutionalizing The CDIO Standards: From a Cascade to an Agile Improvement Model. *Proceedings of the 8th International CDIO Conference*, Queensland University of Technology, Brisbane, July 1 - 4, 2012

Scheiter, K., Gerjets, P., Vollmann, B., & Catrambone, R. (2009). The impact of learner characteristics on information utilization strategies, cognitive load experienced, and performance in hypermedia learning. *Learning and Instruction*, 19(5): p. 387-401.

Shooshtari, Z. G., & Mir, F. (2014). ZPD, Tutor; Peer Scaffolding: Sociocultural Theory in Writing Strategies Application. *Procedia - Social and Behavioral Sciences, 98*, 1771-1776. doi: https://doi.org/10.1016/j.sbspro.2014.03.605

Slater, C. E., & Cusick, A. (2017). Factors related to self-directed learning readiness of students in health professional programs: A scoping review. *Nurse Education Today, 52*, 28-33. doi: https://doi.org/10.1016/j.nedt.2017.02.011

Sweller, J. (1994). Cognitive Load Theory, Learning Difficulty and Instructional Design. *Learning and Instruction*, 4.

Sweller, J., van Merriënboer, J.J.G., & Paas, F. G. W. C. (1998). Cognitive Architecture and Instructional Design. *Educational Psychology Review, 10*(3).

Tasir, Z. & Pin, O.C. (2012). Trainee teachers' mental effort in learning spreadsheet through self-instructional module based on Cognitive Load Theory. Computers & Education, 59(2): p. 449-465.

Van Gerven, P.W.M., Paas, F.G.W.C., van Merriënboer, J.J.G., & Schmidt, H.G. (2002). Cognitive load theory and aging: effects of worked examples on training efficiency. Learning and Instruction, 12(1): p. 87-105.

Zeng Qiangyu, Jiang Juanping & Wang Lijuan (2015). Construction of Engineering Education Teaching Mode based on CDIO-Taking Principles of Atmospheric Detection as an Example. *Proceedings of the 11th International CDIO Conference*, Chengdu University of Information Technology, Chengdu, Sichuan, P.R. China, June 8-11, 2015.

Zhoc, K. C. H., & Chen, G. (2016). Reliability and validity evidence for the Self-Directed Learning Scale (SDLS). *Learning and Individual Differences, 49*, 245-250. doi: https://doi.org/10.1016/j.lindif.2016.06.013

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