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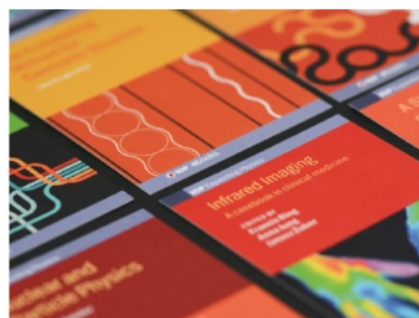
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Development and validation of climate change system thinking instrument (CCSTI) for measuring system thinking on climate change content

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Abstract. The Climate Change System Thinking Instrument (CCSTI) is developed to measure a system thinking ability in the concept of climate change. CCSTI is developed in four phase's development including instrument draft development, validation and evaluation including readable material test, expert validation, and field test. The result of field test is analyzed by looking at the readability score in Cronbach's alpha test. Draft instrument is tested on college students majoring in Biology Education, Physics Education, and Chemistry Education randomly with a total number of 80 college students. Score of Content Validation Index at 0.86, which means that the CCSTI developed are categorized as very appropriate with question indicators and Cronbach's alpha about 0.605 which mean categorized undesirable to minimal acceptable. From 45 questions of system thinking, there are 37 valid questions spread in four indicators of system thinking, which are system thinking phase I (pre-requirement), system thinking phase II (basic), system thinking phase III (intermediate), and system thinking phase IV (coherent expert).

1. Introduction

Reduction method is the most dominant method in scientific learning which is the complex material structure divided and analyzed separately. For example, learning the theory of evolution is not involved in heredity theory which becomes the foundation in evolution, or in learning an external respiratory system, heart and red blood cell are not involved [1-4]. When the system content is learned with reduction method, student will incapability in learning the relationship between components in the system, understanding interaction pattern from a system, modelling a system, even predicting and retrospection a system [5-8]. The same thing also happens to the learning of climate change content.

Climate change is a complex material content and it involves components of the atmosphere, hydrosphere and sea, lithosphere, biosphere, and cryosphere. The material complexity of climate change is very infinite that Keohane calls it as "*Interdependent Regime Complex*" [9]. However, its learning at school does not exceed the circle of cause and effect at the materials explained incoherently in several sub-subjects, such as air pollution, the processes happening on Earth, and the effect of technology and life in the lithosphere. It is not surprising if pre-service teachers, as well as science teachers, have misconception on climate change like equalizing climate change and global warming, and believing that



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¹ CO₂ is the only factor that causes climate change [10]. This is not too different with a research conducted in America [10-12], Science teachers and students in Turkey [13,14], people in Norway [15], and Canada [16]. Shepardson proposed a system based climate learning curriculum with sub-subjects based on sub-components of the climate system [11]. However, that thing will not influence much if the evaluation instruments used is nothing more than a concept mastering only, because student orientation of learning in the classroom can be seen from their questions like, "is this kind of question will appear on the test?".

A research that measures system thinking ability is conducted using patterned multiple choice [8], observation and interview [3,17], through case study [18,19] and Repertory Grid [20] as well as using Likert scale [21]. Several types of research have developed measurement device for system thinking including in medical field [22,23], government and socio-technology field [24,25] and family psychology [26]. Almost every researcher agrees to use diagram and concept map in an assumption that system thinking is related to perception and mental model [27]. However, the use of diagram and concept map in system thinking is not able to measure student ability in making model and pattern as well as predicting and retrospecting. This article explains about development and process of standard system thinking measurement instrument in climate change content with multiple choice questions form.

The term "thinking" shows that its field is in the cognitive process, even though [28] proposed the term "system competency" so that it is not only in cognitive aspect but also in problem-solving ability and vocational expertise which are more difficult. System thinking is a kind of complex thinking and a part of critical thinking [29]. While [30] illustrated like in Figure 1.

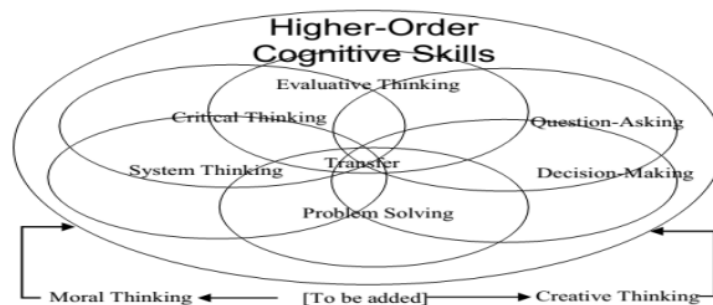


Figure 1. System thinking position in Higher Order Thinking [30]

There are three kinds of system thinking that have been developed, started firstly by Weiss when conducting a research about butterfly response to light and gravity. According to Weiss, regulation and adaptation are reactions of a signature system of the organism [2]. Almost the same time, Bertalanffy saw that the system was parts of the element which is connected with each other simultaneously through a circle [5,31]. This system thinking later inspired other fields when Bertalanffy met Kenneth Boulding (economist), Anatoli Rapoport (mathematician) and Ralf Gerard (psychologist). Bertalanffy's theory of system thinking was named GST (General System Thinking).

Although appeared almost simultaneously with GST, Weinert claimed cybernetic system thinking. The theory of cybernetic system thinking happens in a stable and closed environment in a long time period. Another scientist who proposed theories of system thinking was Forrester. According to Forrester, the system was open and always tried to reach balance even in a limited period. System balance was temporary and there would be a chaos phase that caused predictability of future to become very limited while system thinking developed by Forrester tends to ignore structures and functions because in dynamic system thinking, structure and functions do not stay, always develop and evolve to reach balance. Several researchers tried to develop their own dimensions by using theory framework of GST, cybernetic, or dynamic [8,20,32,33,34]. Boersma [35] then combined the three frameworks in a

1 continuum arrangement, which is GST, Cybernetic, and dynamic system. This is a bit different from the one proposed by Arnold and Wade [36] who put the position of dynamic thinking as the middle level of system thinking. The framework of system thinking from Boersma is the one that is developed into an indicator of system thinking in this research.

2. Methods

Development CCSTI use four steps of developmental research by Akker [37]. The data are collected randomly from 68 volunteers in three departments (Biology education, physic education and chemistry education). The indicators of system thinking developed based on Boersma's framework are mapping into four levels pre-requirement, basic, intermediate, and expert. The readability level test involved 10 college students majoring in Physics Education and Biology Education are then processed by expert validation. The expert validation is performed by five lecturers who are experts in assessment and evaluation as well as in Geo-Science. The data of expert validation are analyzed using CVR developed by Lawshe [38]. Empirically field to be analyzed by using SPSS series 18.

3. Result and Discussion

3.1. Instrument draft development

Based on the mapping results of GST, Cybernetic and Dynamic system thinking theory framework at early, the indicator of system thinking was built into four indicator, system thinking Indicator I (pre-requirement), system thinking Indicator II (basic), system thinking indicator III (intermediate), and system thinking indicator IV (coherent expert). The results of the mapping are developed in indicators such as in Table 1.

Table 1. System thinking indicators

Level	System Thinking Indicators	
I	A	Able to identify components and processes in a system. Able to identify components like atmosphere, geosphere, cryosphere, hydrosphere, biosphere, and the processes in them if related to climate system
	b.	Able to identify the relationship of structures and functions/roles in system components in one level of organization
	c.	Able to map climate phenomenon/concept in specific components of the climate system.
II	a..	Able to analyze the relationship of concepts on one level with another level above or another level below.
	b.	The ability to organize components of system, processes, and interactions among them in one system frame
	c.	Able to identify process of feedback which happens to the system
III	a.	Able to make generalization from the pattern shaped by the system
	b.	Able to design an interaction pattern from the system components whose existence in a closed system can be detected
	c.	Able to make/develop models that illustrate the positions of all components in a closed system framework in 2D/3D whether they are horizontal or vertical
IV	a.	Predict/Retrospect behaviors which appear from the system due to interactions among components in the system
	b.	Predict/retrospect the effects which appear from the existence of intervention towards the system (such as the loss/addition of system components) by using model or pattern which has been designed
	c.	Implement new system pattern based on the result of prediction/retrospection

1

3.2. Readability Test

The indicators developed into 47 questions are then tested for their readability to 5 college students majoring in Physics. The readability test is conducted by interview and the most results of the readability test show that they have many difficulties in terms and abbreviations that are new to them, such as GHG which is an abbreviation of Glass House Gas, Retrospection, Urban Heat Island, Albedo, Precipitation, Cryosphere, Eutrophication, Carbon Sinker, Sunspot, and Coral Bleaching. To solve that problem, those terms are partnered by words or sentences similar to the question discourse.

3.3. Expert validation

The expert validation phase is performed after question readability test. The analysis of question validation uses Content Validity Ratio (CVR) which was developed by Lawshe (1975)[38]. The process of expert validation involves 5 lecturers from three universities, including ITB, UPI, and UNSRI. To measure the CVR of each component, two criteria are used, including value 1 if the developed question item is relevant with the question indicators and value 0 if the question item is not relevant. From the CVR score of experts, there are 45 questions with 2 questions erased and the total CVR score obtained is 40.4 and the Content Validation Index (CVI) is 0.86, which means that the questions developed are categorized as very appropriate with question indicators. Besides the erasure of the 2 question items, other questions also get advice from validators, such as improvement in their sentences on the discourse, in the question items and/or options whose examples can be seen in Table 2.

Table 2. Description of the improved question examples.

Item question before validation	Item question after validation
<p>Item No.10</p> <p>Based on the text above, the correct analysis of the dominant relationship of global warming and rainfall in Asia region is...</p> <p>A. Tropical (humid and hot temperatures) Asian regions plus global warming increase the potential for convective clouds to emerge</p> <p>B. Due to global warming, Asia has a high intensity of sunlight so it potentially turns water into steam</p> <p>C. Global warming increases the intensity of the sunlight that increases water evaporation and rainfall</p> <p>D. Global warming increases the intensity of solar radiation, which increases the evaporation of relatively large amounts of water in Asia</p>	<p>Item No. 10</p> <p>Based on the text above, the correct analysis of the dominant relationship between global warming and the rain in Asia region is...</p> <p>A. Tropical (humid and hot temperatures) Asian regions plus global warming increase the potential for convective clouds to emerge</p> <p>B. Areas of Asia that have a high intensity of sunlight and global warming increase the potential to convert water into steam</p> <p>C. Global warming increases the intensity of the sunlight so it increases water evaporation and rainfall</p> <p>D. Global warming increases temperature and the amount of core condensation and rainfall</p>
<p>Item No.30</p> <p>If the use of AC is not a solution to overcome the discomfort caused by urban heat island; based on the behavior prediction/retrospection arising from an interaction between components in the system, you can offer the following preventive solutions, except...</p> <p>A. increasing the number of wide-canopied trees to enlarge albedo and reduce the</p>	<p>Item No.30</p> <p>If the use of AC is not a solution to overcome the discomfort caused by urban heat island (UHI) then based on the prediction/retrospection on interactions between components in the system, which statement is NOT a solution that can be offered to overcome UHI?</p> <p>A. increasing the number of wide-canopied trees to enlarge albedo and reduce the</p>

Item question before validation	Item question after validation
absorption of solar radiation by the geosphere	absorption of solar radiation by the geosphere
B. using bright colors on the streets and buildings to increase the number of albedos	B. using bright colors on the streets and buildings to increase the number of albedos
C. reducing the use of fossil fuel and using of household waste biogas to limit GHGs	C. reducing the use of fossil fuel and using household waste biogas to limit GHGs
D. creating regular waterways and preventing garbage disposal to the waterways	D. creating regular waterways and prevent disposal of garbage into them

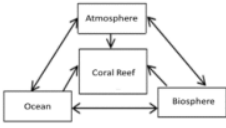
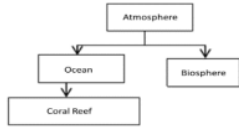

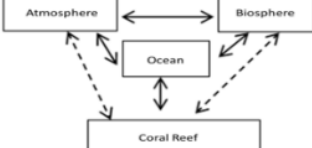
3.4. Reliability Test

The 45 questions are tested empirically to 67 college students majoring in Biology, Physics, and Chemistry Education on two LPTKs. The results are then analyzed statistically using SPSS version 18 and it is obtained that 8 or 45 question are erased so that the questions used are 37 question with readability level 6.05. According to Glyn, readability score or 0.6-0.69 is a quite good score and can be accepted [39]. These criteria are based on De Vellis [40] who stated that Cronbach's alpha > 0.80 is very good; 0.7-0.8 is categorized as "respectable"; 0.6-0.69 is categorized as "undesirable to minimal acceptable"; while <0.6 is categorized as "unacceptable".

The question spreading in the indicators of system thinking and internal ability score on each system thinking criteria can be seen in Table 3.

Table 3. Indicator of system thinking, sample question and reliability score

Indicator	Sample Question	Reliability Score
I	Based on the text above, which component of the climate system causes the LPTM event and what does it affect? A. Geosphere and it affects atmosphere, biosphere, cryosphere and hydrosphere B. Atmosphere and it influences biosphere and hydrosphere C. Hydrosphere (ocean) and it affects atmosphere and biosphere D. The cryosphere and the affected are all components of the climate system	6.26
II	Based on the text above, the analysis of the relationship between global warming and the dominant rain in Asia region is... A. Tropical (humid and hot temperature) Asian regions plus global warming increase the potential for convective clouds to emerge B. Areas of Asia that have a high intensity of sunlight and global warming increase the potential to convert water into steam C. Global warming increases the intensity of the sun which increases water evaporation and rainfall D. Global warming increases temperature, the amount of condensation core, and rainfall	6.08

1 Indicator	Sample Question	Reliability Score
III	Which illustrates the pattern of interaction among the other components involved in the text above?	6.03
	<p>A. </p> <p>B. </p> <p>C. </p> <p>D. </p>	
IV	<p>If the human need for energy turns the Polar Regions into mining areas, then which of the graphs above is the pattern of the prevailing climate system when it occurs?</p> <p>A. Like the mid-1700s model by enlarging the circle of ocean and sea ice</p> <p>B. Like the TAR model by increasing the influence of Dynamic vegetation circle</p> <p>C. Like AR4 and AR5 models</p> <p>D. Like the AR5 model by enlarging the circles of dynamic vegetation and atmospheric chemistry</p>	6.25

4. Conclusion

The CCSTI developed are categorized as very appropriate with Cronbach's alpha about 0.605 which mean categorized undesirable to minimal acceptable. From 45 questions of system thinking, there are 37 valid questions spread in four indicators of system thinking, which are system thinking indicator I (pre-requirement), system thinking indicator II (basic), system thinking indicator III (intermediate), and system thinking indicator IV (coherent expert).

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