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THE ROLE OF RESEARCH-BASED CURRICULAR UNIT ON STUDENTS' SYSTEMS UNDERSTANDING OF HUMAN IMPACT ON THE ENVIRONMENT

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Abstract: The research-based curricular unit presented in this proposal is a response to the new tide of educational reforms in the United States. This curricular unit represents an attempt to frame K-12 science curriculum around three dimensions: crosscutting concepts, disciplinary core ideas and scientific practices recently released in the report on a Framework for New K-12 Science education (National Research Council, 2012). Integration of three dimensions into the development of agriculture-related curricular unit reflects complexity and logic inherent in science education facilitating systems understanding of environmental issues. The development of this learning unit takes place under the initiative of the National Science Foundation (NSF) funded project to explore the efficacy of the agriculture-related unit on high school students' systems understanding of the human impact on natural systems. The presented unit embodies characteristics that identify research-based curricular unit (Clements, 2007). Preliminary results presented in this study demonstrate potential of close adherence to features identifying research-based curriculum in supporting systems understanding of environmental problems. Mediation results of this nature have larger implications on future efficacy of curriculum intervention.

***Keywords*: Crosscutting concepts, disciplinary core ideas, systems understanding**

Introduction

Educational Standards

The ongoing development of the curricular unit presented in this proposal is a response to the demand of framing K-12 science curriculum around multiple dimensions recently released in the report on a *Framework for New K-12 Science Education* (National Research Council [NRC], 2012), which served as a foundation for the development of *Next General Science Standards (NGSS*; NGSS Lead States, 2013). Articulating science standards has been central in creating a vision of what subject matter content had to be taught and identification of learning goals (Clements, 2007; Krajcik et al., 2008). To that extent, national science standards have historically served as a starting point in identifying scientific ideas that would optimally contribute to the development of students (Krajcik et al., 2008). However, the translation of science standards into curriculum materials is not without challenges. Multiple aspects need to be taken into consideration when framing curriculum around standards (Debarger et al., 2016; Taylor et al., 2015). With the release of the *Next Generation Science Standards (NGSS*; NGSS Lead States, 2013) emerged the need to integrate new disciplinary core ideas, crosscutting concepts, and scientific practices into the curriculum design (Debarger et al., 2016; Taylor et al., 2015).

In the current study, we draw parallel between these three dimensions and features that identify research-based curriculum to outline potential avenue for the development of the learning unit that promotes integrated vision of agricultural impact. Thus, crosscutting concepts exemplify intellectual tools by which scientists connect

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scientific ideas across science disciplines (Krajcik et al., 2014). For instance, *cause and effect, or systems* crosscutting concepts serve as unifying themes by which scientists connect scientific ideas. To that extent crosscutting concepts represent syntactic structure of science that is reflected in the hierarchical representation of disciplinary content consistent with the logic of science (Fenstermacher, 1980). Disciplinary core ideas are central to each science field as they provide an explanation for a host of discipline-specific phenomena (Krajcik et al., 2014). For instance, *Human Impact on Earth Systems* is a disciplinary core idea that explores influences of human actions on the environment and requires students to engage in evidence-based scientific practices in order to counteract adverse effects of poor management of planetary resources (NRC, 2012). The impact of intensive agriculture on the environment provides a relevant example of human-induced influence on natural systems communicated in current educational reforms and a real-life context to investigate mechanism underlying this interference. This paper argues for the integration of *NGSS* standards into curriculum development as the potential avenue for a design of research-based curricular unit that supports systems understanding of environmental issues (Taylor et al., 2015).

Systems Understanding

Despite the growing recognition and interest towards systems thinking, little is known about the ways to assist students in developing systems understanding (Kali, Orion & Eylon, 2003). This interest stems from advantages that systems thinking offers to the field of education (Kali et al., 2003). To develop an understanding of systems thinking, we need to provide a departing definition for systems. Definition of systems by O'Connor and MCDermott (1997) presents system as an entity that maintains its existence and functions as a whole through the interaction of its parts. The difficulty of understanding complex systems is evident in students of all ages (Assaraf & Orion, 2005; Kali et al., 2003). It has even been argued that systems thinking is an innate ability rather than something that can be taught (Gudovich, 1997). Yet another camp of researchers address ways of overcoming student tendency to compartmentalize knowledge (Assaraf & Orion, 2005; Kali et al., 2003; Orion, 2002). These researchers argue that students rarely spontaneously integrate knowledge presented in isolation and need to be assisted in integrating knowledge and developing systems understanding of complex scientific phenomena (Songer & Linn, 1991). Despite the obvious advantages that systems understanding has to offer, its potential remains largely unexplored in science education (Kali et al., 2003). The need to explore the potential of developing systems understanding among students becomes even more critical during the current educational paradigm emphasizing complex environmental issues in the science curriculum (Assaraf & Orion, 2005).

A new vision set forth by The National Research Council's *Framework for K-12 Science Education* (NRC, 2012) focuses on smaller number of disciplinary core ideas (DCI) that creates space to explore particular phenomena using crosscutting concepts. Crosscutting concepts, such as *cause and effect* or *systems*, serve as intellectual tools by which scientists explore fundamental aspects of the nature and connect important ideas across all science disciplines. Use of crosscutting concept exploring causal relationships between materials allows students explore processes at the lower level in order to provide explanations for observable macroscopic phenomenon (Williamson, 2011). This use of crosscutting concepts as the way to explore mechanism underlying human impact on the environment closely parallels the definition for skills that promote system-thinking: (a) understanding the parts of a system, (b) understanding the connections/process among these parts, and (c) understanding the system as a whole (Kali et al., 2003). Research-based curricular unit presented in this paper closely adheres to the level definition of system-thinking skills by exploring crosscutting concept of causal relationships within biogeochemical cycles to uncover mechanism and facilitate systems understanding among students.

Critical Features Identifying Research-Based Curriculum

Educational scholarship recognizes constructivism, coherence, and 'educativeness' as three critical characteristics identifying research-based curriculum (Clements, 2007; Taylor et al., 2015). In arguing for the adherence to these characteristics during curriculum development, we draw heavily on the main general principles inherent in Curriculum Research Framework (CRF) developed by Clements (2007) and proposed for the construction of research-based curriculum in science education. While developing theoretical underpinnings for the features of research-based curriculum we explore the extent to which they overlap with the three dimensions.

Intersection of Constructivism and Crosscutting Concept Dimension

Recent re-emphasis in cognitive psychology on the active role students play in constructing knowledge individually and by interacting with the social community has spawned a renewed interest toward constructivism and its potential in contributing to curriculum theory and practice (Osborne, 1996). Much of the newly embraced constructivism emphasizes the importance of social interaction that generates a community of inquiry. However, as inspiring as social constructivism sounds, it fails to provide any specific guidelines for creating communities of inquiry (Osborne, 1996; Terwel, 1999). Research categorizes different interpretations of constructivism and inconsistency of vision surrounding its role in education as key reasons for this lack of specificity in identifying guidelines under which a community of inquiry can flourish (Terwel, 1999). As a result, researchers resort to the description of ideal educational circumstances under which constructivism could be utilized to its optimal potential (Taylor et al., 2015; Terwel, 1999). According to Clements' CRF (2007), the instructional model defines the sequence of activities structured in accordance with the model of students' cognition based on the principles of constructivism. Therefore, employment of various learning models, such as the 5E or its predecessor the Learning Cycle, is a main path in which research on curriculum development attends to constructivist learning (Taylor et al., 2015).

Similar to constructivism, crosscutting concepts represent strategies attending to general epistemology of knowledge construction, for they apply to all sciences and address the way humans attempt to understand the fundamental aspects of nature (NRC, 2012; Sandoval & Reiser, 2004). The emphasis on the overlap between constructivism and crosscutting concepts underscores the importance of utilizing crosscutting concepts during the process of curriculum development as the dimension attending to the principles of constructivist learning. The implication of this connection should reflect on the way curriculum developers and teachers structure curricular components and arrange sets of activities into an instructional sequence (Taylor et al., 2015). Throughout the sequence of cognitive tasks, students apply the canonical strategy of establishing patterns or causal relationships and learn to recognize similarities among science disciplinary core ideas that are united by the means of crosscutting concepts, thus attending to general epistemological commitments of constructivism reflected in *NGSS* (NRC, 2012; Osborne, 1996; Sandoval & Reiser, 2004).

Intersection of Coherence and Disciplinary Core Ideas

Although general epistemological commitments are consistent with principles of constructivism, they lack key organizing concepts of a particular single discipline that typify the discipline-specific concepts involved in descriptions, explanations, and predictions of natural phenomena (Krajcik et al., 2014; Sandoval & Reiser, 2004). As the dimension central to each science, disciplinary core ideas provide an explanation for a host of discipline-specific phenomena and typify substantive structures that ensure coherence in the discipline (Krajcik et al., 2014). Therefore, it is through the adherence to disciplinary core ideas that curriculum developers would be attending to the coherence of the research-based curriculum materials (Taylor et al., 2015).

In promoting coherence, curriculum developers arrange learning activities within coherent conceptual framework that reflects the logic of the science discipline from which the subject matter derives (Schmidt et al., 2005; Taylor et al., 2015). Similarly, Clements' CRF defines subject natter as a foundation that plays central role in generating students' development of future understanding (Clements, 2007). Adherence to the conceptual framework becomes instrumental in integrating disciplinary core ideas with scientific practices and unifying crosscutting concepts while coordinating learning goals, cognitive tasks and assessments (Krajcik et al., 2014). One of the ways of strengthening coherence of the curriculum development process is the use of conceptual flow graphics (CFGs) (Taylor et al., 2015). Curriculum developers use CFGs to overlay a constructively arranged sequence of cognitive tasks with disciplinary core ideas creating conceptual storyline (Fig. 1).

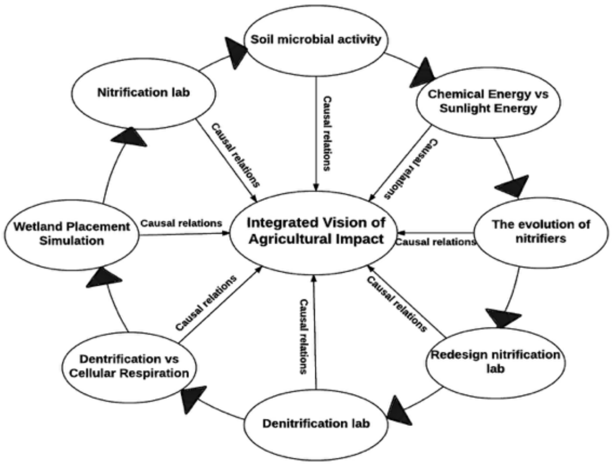

Figure 1. Conceptual Flow Graphic (CFG) of the activities

Adherence to 'Educativeness'and Carving Space for Collaboration

Clements' framework refers to 'educativeness' as 'educationally effective' achieved via employing certain pedagogical strategies (Clements, 2007). Clements' substantiation of 'educationally effective' draws upon the research that discuss instructional strategies emphasizing conceptual development (Hiebert, 1999; Schneider et al., 2005). Following Clements' substantiation of 'educativeness', we ground the discussion on 'educativeness' of curriculum materials by focusing on the explicit teacher support for learning, such as pedagogical support, which is embedded in the curricular materials (Schneider & Krajcik, 2002; Taylor et al., 2015). However, current research points to the imminent tension arising as a result of having to incorporate particular curriculum despite clear pedagogical support (Krajcik et al., 2008; Taylor et al., 2015).

Professional development and collaboration can mitigate this tension by providing opportunity for teachers to study materials thus increasing teachers' knowledge of the rationale underlying instructional decisions embedded in the curricular materials (Taylor et al., 2015). Collaboration opportunities provide teachers with higher level of engagement, which leads to frequent interactions with curriculum materials and teachers' improved ability to design tasks and questions that would promote student thinking (Webb, 2005). Therefore, professional development and collaborative learning with the curriculum developers carve the space for teachers to interact with the educative nature of curricular materials and to take full advantage of research-based curriculum materials. These collaborative learning opportunities and educative provisions should account for potential difficulties that teachers face when adapting curriculum materials into their existing curricular repertoire (Davis & Krajcik, 2005; Remillard, 1999).

Method

Participants

The study was conducted in a paired pre-test-post-test design with 31 senior high school students enrolled in the elective course of ecology at Mankato East High School. Majority of the students 28 out of 31 had General Biology background. 3 students out of 28 had Chemistry background. The school is located in Blue Earth County which has been under intensive agricultural development.

Research-Based Curricular Unit

The agriculture-related curricular unit developed for this study coordinates leaning goals, cognitive tasks and assessments around *NGSS* dimensions and exemplifies a tension between social system and the environment (NRC, 2012). The unit includes lab studying the intersection of two biogeochemical cycles (nitrogen and carbon) and the use of agriculture-related software simulation interspersed with discussion and knowledge integration activities. The implementation of this learning unit took place after 10 lessons committed to traditional approach of rote memorization towards learning carbon and nitrogen cycles in isolation. The aim of this study was to investigate the influence of a research-based learning unit in mediating students' systems understanding of human influence on water quality and greenhouse gas effect.

Attendance to Critical Features During the Development of Agriculture-Related Unit

As an educational offshoot of the NSF funded research project, the proposed agriculture-related unit stems from the collaborative efforts between the science education researcher and high school biology teacher. The significance of sound understanding of environmental problems becomes central for citizen participation in addressing issues stemming from human interference with natural systems (Mohan et al., 2009; Gunckel et al., 2012). Therefore, in order to gain agency in evidence-based decision-making on environment-related issues from a scientific perspective, students need to develop integrated understanding of the agricultural impact on ecological systems.

Attendance to Coherence and Disciplinary Core Ideas

Selection of agricultural impact on the environment resonates with the environmental challenge relevant to students' community which provides the potential for significant environmental education and defines substantive structures creating conceptual storyline. Thus, integration of disciplinary core idea of *Human Impact on Earth Systems* ensured attendance to the feature of coherence during the development of the unit Krajcik et al., 2014; Osborne, 1996). One of the nutrients implicated in the impact of agriculture is nitrogen. The unit intended to explore molecular components involved in the nitrogen cycle and variables that influence the processes connecting these components within the context of agriculture. Since biogeochemical cycles do not operate in isolation, the unit focused on the intersection of the nitrogen cycle with the carbon cycle as a mechanism underlying agricultural impact on the environment.

Attendance to Constructivism and Crosscutting Concepts

By engaging crosscutting concept of *cause and effect*, unit attended to the general epistemological commitments of constructivism (Sandoval & Reiser, 2004). By exploring causal relationships linking molecular components of the nitrogen cycle and carbon cycle, students discover biological processes that link molecular components. Such an approach intends to facilitate students' understanding of lower level activities and encourage students to use causal relations to construct evidence-based explanations about higher level observable phenomenon (Williamson, 2011). Detailed study of an intersection of two biogeochemical cycles that accounts for variations in the interactions among molecular components helps to promote understanding of a feedback loop that connects the cycles with the environment (Raia, 2008).

Attendance to 'Educationally Effective' Pedagogical Support-Collaboration

The ongoing collaboration between the high school biology teacher and the researcher has been critical in helping the teacher develop more content specific knowledge on ecological concepts that the teacher previously considered outside of her expertise area. This collaborative experience provided the teacher with opportunities to study the materials and to make instructional decisions regarding the arrangement of the cognitive tasks, instilling the teacher with the sense of ownership of the curriculum materials that will be implemented in spring 2017 (Davis & Krajcik, 2005; Schneider & Krajcik, 2002). The critical importance of collaboration between the teacher and the researcher has been especially pronounced during the collaborative development of questions and tasks to accompany a software simulation exploring the effectiveness of wetland construction. This computer-based simulation is based on the rate of denitrification of the local watershed. Research indicates the advantage of using computer-based simulations in manipulating variables that are outside of user's control in the natural world (Huppert et al., 2002; Trey& Khan, 2008). To such extent the use of this computer simulation intends to promote students' sense of agency in implementing the best land use management practices. At the same time, the effective use of computer simulation is closely connected to the teacher guidance that supports the simulation use (Sandoval & Reiser, 2004; Webb, 2005). The ongoing collaboration with an active involvement of an expert scientist aims to develop a set of questions and tasks to facilitate students' ability in constructing explanations on wetland effectiveness by eliciting evidence-based causal links highlighted throughout the curricular sequence. These collaborative learning opportunities with curriculum developers enable the teacher to capitalize on the embedded educative nature of the unit materials and to participate in the development of cognitive tasks that encourage systems understanding of environmental issues.

Results and Discussion

Pre and post data collected included pre-structured concept maps, free-flowing connection diagrams and written essay concerning the implications of intensive agriculture and wetland as a strategy to counteract those influences and is available only for 24 students out of 31. Preliminary analysis presented in this study focused on the pre and post results of pre-structured concept maps. Pre-structured concept maps included molecular components and macro-level components involved in nitrogen and carbon cycle. Macro-terms, such as plant, amphibians and soil organic matter identify living and non-living entity which connect two cycles at a very conceptual macro-level.

Average number of connections between nitrogen containing molecular components and macro-level entities have increased significantly from pre to post assessment, which at the very least indicates higher efficacy of the research-based unit in comparison to canonical rote memorization. More interesting results show increased number of connections linking molecular components from two cycles-nitrogen and carbon. Students who had higher number of connections linking molecular components from nitrogen and carbon subsystems (cross cycle), demonstrated appreciably higher number of links connecting molecular components within nitrogen cycle (Fig. 2). Conversely, majority of the students who have made higher number of nitrogen connections by linking molecular components that belong within nitrogen cycle to each other, were more likely to connect molecular components belonging to two separate cycle (cross cycle connections). An interesting finding shows that not all students who successfully linked two cycles on the molecular level connected molecular components within the nitrogen cycle. This anomaly requires further investigation to see what other connections might be conducive to the improved understanding of cross cycle connections at the molecular level. These connections are particularly interesting because they reflect links between cycles and potentially indicate systems understanding on the molecular level.

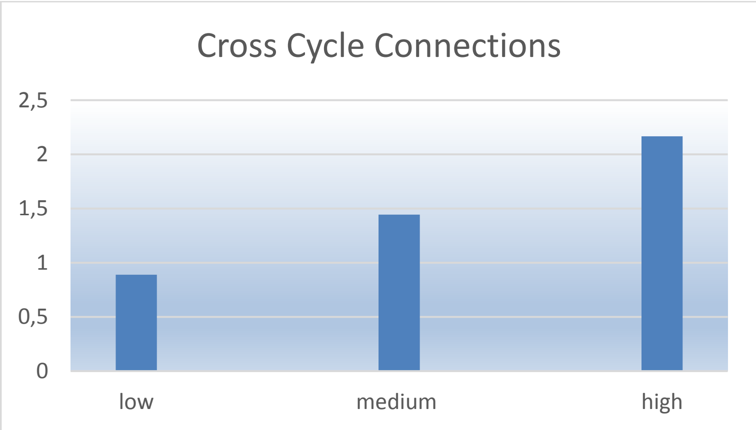

Figure 2. Categories of students based on cross cycle connections

In order to connect the understanding of these processes within biogeochemical cycle with the systems understanding of the agricultural impact on the environment, we need to further our analysis and triangulation of the results from concept map analysis with other pieces of assessment.

Conclusion

This research project intends to explore the avenue of framing curriculum around multiple dimensions recently released in the report on a *Framework for New K-12 Science Education* (NRC, 2012). This study argues for a close parallel between three dimensions and the features that identify research-based curriculum. Moreover, integration of new dimensions into the curriculum holds potential for promoting systems understanding among students. This possibility of developing systems understanding is more promising under the greater emphasis on environmental awareness since systems understanding translates environmental problems into more coherent understanding of the environment (Assaraf & Orion, 2005). The uniqueness of this study stems from testing the impact of coherent agriculture-related curricular unit encouraging students to explore causal links among entities in mapping out the interactive nature of nutrient cycles underlying the human interference with natural systems (Williamson, 2011). The interdisciplinary nature of this project has the potential to show how close adherence to features identifying research-based curriculum and collaborative learning opportunities can support development of coherent curricular unit mediating students' integrated vision of environmental issues. Having coherent curriculum materials consistent with educational reforms and a teacher prepared to use these materials in an intended manner are critical in enacting opportunities that mediate considerable impact on students' conceptual understanding. Mediation results of this nature have larger implications on future efficacy studies of curriculum intervention.

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