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Understanding Students' Global Interdependence in Science Instruction

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Abstract

Multiple American educational organizations such as the National Education Association, Association for Supervision and Curriculum Development, and the Council of Chief State School Officers have advocated for globalizing the K-12 curriculum. The National Science Teaching Association (NSTA) in a position statement on international education and the Next Generation Science Standards have produced goals and standards for internationalizing the science curriculum by addressing topics such as climate change, environment, and disease that cross borders. In contrast to those pronouncements on the curriculum, this article views global science education through an instructional lens that focuses on a students' global interdependence in science continuum allowing researchers and casual observers to classify science classroom activities into one of five stages based on the interdependence during instruction of students in two or more countries. At the continuum's lowest stage labeled isolated, instruction is contained within a classroom with students having no interaction with students in another country. At the highest end called collaborate, students in two or more countries are working jointly to co-create a solution to the task before them. This science education continuum can also be used to categorize technology and engineering activities and could be adapted for use in other curricular areas including mathematics, language arts, and social studies, used as a tool to complement scholarship about a range of education topics from social justice to curriculum to student motivation, or inform pre- and in-service teacher education.

Keywords: global education, science education, global collaborative education, citizen science

Introduction

Global education's importance for America's contemporary K-12 students, whose lives will span much of the 21st century, has been affirmed by multiple organizations from science education specific societies, such as the National Science Teachers (now Teaching) Association (NSTA) (2017), to education practitioner organizations, such as the Association for Supervision and Curriculum Development (n.d.) and the National Education Association (n.d.), to policy making societies, such as the Council of Chief State School Officers (CCSSO) in cooperation with the Asia Society (Mansilla & Jackson, 2011). At the international level, the Organization for Economic Cooperation and Development's (OECD) Programme for International Student Assessment (PISA) has initiated a world-wide round of testing to ascertain students' global competency (OECD, 2020; Ramos & Schleicher, 2018).

In addition to national and international organizations, American states, typically taking a 21st century jobs perspective, have expressed interest in their students becoming globally competent. The state of North Carolina has moved forthrightly to produce globally competent high school graduates (North Carolina State Board of Education, 2013). As part of its certification program, teachers can earn a Global Educator Digital Badge by completing (a) 100 hours of professional development focused on global education plus (b) a *capstone project* in the form of globally oriented instructional units that will become available within the school district and around the state for use by other educators (North Carolina Department of Public Instruction, 2018). Additionally, North Carolina schools and districts can earn recognition as being globally ready by, for example, offering world languages K-12, creating means for teachers and administrators to earn global badges, entering into global school partnerships, and passing school board policies regarding global education.

The NSTA (2017) statement's first sentence, "NSTA encourages and promotes international science education on all levels from PreK to post-secondary", (p. 1) declares the significance of international science education at all grade levels from preschool to the university. The statement goes on to encourage science educators in all settings to "engage in international collaborations to improve the quality of formal and informal science teaching and learning" (p. 2). However, the NSTA statement does not describe or prescribe any specific teaching methods to carry out global science education.

From the curriculum perspective of what topics should be addressed in science teaching, global science education means, to some, teaching about topics and issues that impact many, if not all countries. NSTA (2017, p. 2) declares that science educators should "raise student awareness of social and international issues and global impact of scientific concepts and concerns" and "provide and use curriculum materials that include an international perspective." In this spirit students are taught about climate change, disease, water quality, environment and other topics that cross national borders. The United Nation's (2015) Sustainable Development Goals provide a list of significant topics, many of which have a science component. America's Next Generation Science Standards (NGSS), for example, in the area of climate proposes students learn in:

- grades 3-5 to "obtain and combine information to describe climates in different regions of the world" (3-ESS2-2 Earth's Systems) (NGSS, 2013a),
- middle grades to "ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century" (MS-ESS3-5 Earth and Human Activity) (NGSS, 2013b), and
- high school to "design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity" (HS-ESS2-4 Earth's Systems) (NGSS, 2013c).

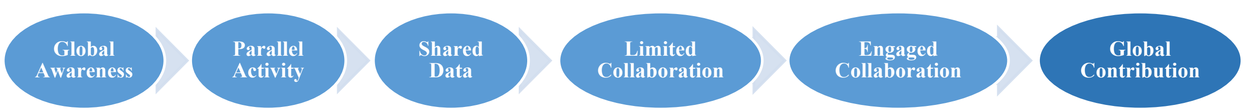
However, instead of a curricular emphasis, this article focuses on global science education through an instructional lens centered on teacher-led student activities in the science classroom. This focus can be restated in the form of a question centered on the student, *What is the student doing during science instruction involving global education?* To answer that question, this article proposes a students' global interdependence in science (SGIS) continuum based on the interdependence during science (or technology or engineering) instruction between students in at least two countries. This continuum draws on social constructivism dating back to Berger and Luckmann's *Social Construction of Reality* (1966) and a host of other theorists such as Vygotsky (1978), but more specifically on Stahl's (2006) computer-supported collaborative learning and group cognition, as will be seen in the continuum's distinction between cooperative and collaborative learning. Since much of contemporary collaborative global learning relies heavily on teachers' and students' use of the Internet, the continuum considers teachers' knowledge of technological pedagogical content knowledge (originally TPCK but now TPACK) (Koehler & Mishra, 2008). Finally, the continuum's *share* stage was importantly informed by Cooper's (2016) description of citizen science.

In the preceding paragraph it should be noted in schooling that technology has two distinctly different meanings. On the one hand, technology refers to instructional technology, the use of computers, the Internet, and other electronics to support instruction regardless of the subject matter, as represented by the International Society for Technology in Education (n.d.). On the other hand, technology refers to a school specific subject area addressing how humans have developed products, such as paper clips, pacemakers, and picture frames, and processes, such as electroplating, beer brewing, and shelving books according to the Dewey Decimal System, to address human needs and desires. The T in STEM, which is an acronym standing for science, technology, engineering, and mathematics, refers to this second meaning of the word technology (Granovskiy, 2018).

The Students' Global Interdependence in Science Continuum

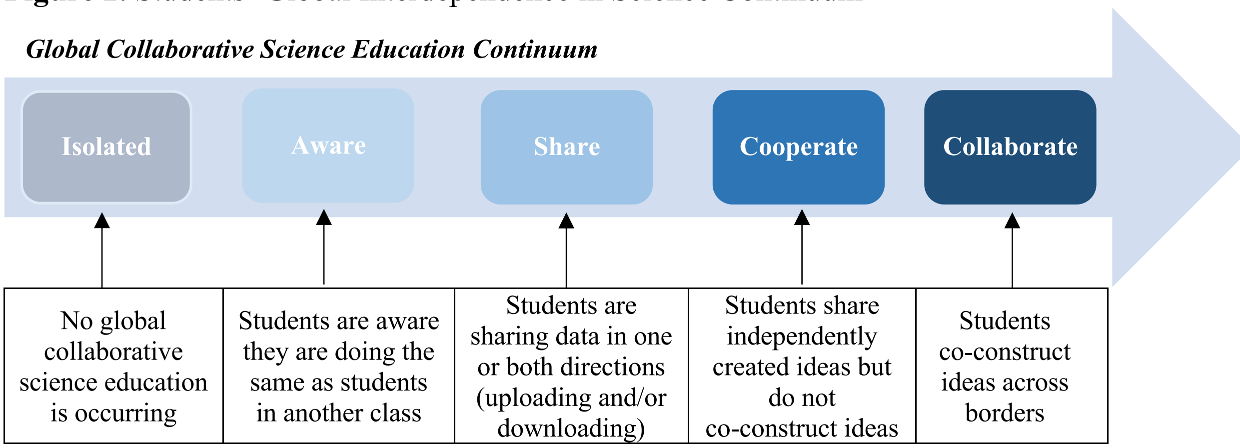
The students' global interdependence in science continuum was developed to serve multiple purposes from teacher education to research. From a teaching perspective, this continuum in an earlier state of development was described by Nugent et al. (2015) to be used to inform science teachers about instructional methods for global science education (See Figure 1). Vocabulary somewhat different than used in this article appeared in the Nugent et al. article and two stages not associated with interdependence, the key variable for this article's continuum, were added. In a stage called *global awareness* teachers were prodded to incorporate global topics in their teaching along the lines proposed by NSTA (2017) and the NGSS Lead States (2013a), but instruction was entirely contained within the classroom walls. At the top end of the continuum a stage called *global contribution* was added to encourage teachers to have their students work across borders with other students on problems contributing to the well-being of humankind. While the Nugent et al. continuum has been found to be valuable for conducting professional development and its global contribution is nearly universally valued, that continuum was not truly a continuum, since it was not based on a single variable. Thus, that continuum was not appropriate for research about students' global interdependence in science.

Figure 1. Global Science Education Continuum Based on Nugent et al. (2015)



The students' global interdependence in science continuum proposed here (see Figure 2) is a true continuum appropriate for researchers in that it is based on a single variable, interdependence (of students from two or more countries during instruction), that varies from no interdependence to total interdependence where students across borders are thinking together in what we refer to as *groupthink*, a term used by Janis (1971), but with a different meaning, and described by Stahl (2006) as group cognition.

Figure 2. Students' Global Interdependence in Science Continuum



A continuum contains no internal boundaries as the variable being portrayed evolves from the zero condition to the top, total end. However, in this article the continuum is depicted as composed of five sections called stages. The continuum is best understood by thinking of two students, one in country A and the other in country B, and considering how much the students are relying on each other for the global instruction taking place within their classrooms. The continuum could be used by a formal researcher of students' behavior within classrooms or, on the other hand, a casual observer, such as a parent, principal, preservice teacher or other person, watching a class to ascertain what is happening.

First, the five stages of the continuum will be described and then a dichotomous key will be presented for use by any observer to classify any science classroom instructional activity into one of the five stages.

Stage 0: Isolated

No doubt in the majority of classrooms students within those walls do not interact during instruction with students from other countries. Students may learn about globally-focused topics such as deforestation of tropical rain forests; but if that instruction does not involve students from other countries, there is no interdependence among students across borders. The instruction within such classes may be superior with the teachers receiving accolades for their instruction, and indeed those honors may be well deserved, but the instruction is self-contained within the classrooms. The teacher may coordinate with other teachers within the school building or across the city, state, or nation to have students, for instance, work together to address an engineering challenge or participate in a science fair. However, in this stage of the continuum if there is no interaction with students in other countries, then the continuum considers those students to be isolated from students in other countries. Thinking in terms of a continuum, this stage represents the null set, the condition where there is no interdependence.

Stage 1: Aware

In some classrooms, students know they and students in at least one other country are doing the same activities. For example, International Baccalaureate (IB) programs are found in over 5400 schools in over 150 countries (IB, n.d.). Students, educators and parents know that all IB schools follow a certain set of guidelines and policies; but unless a teacher or school chooses to do more than follow the IB program, the students in those schools are only aware there are students elsewhere doing something

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somewhat similar to what they are doing. Specifically, in the science field, Google Science Fair (n.d.) and its partners sponsored an international science fair starting in 2011. As with IB, students participating in the Google Science Fair are aware students in many other countries are also taking part; but participants do not interact with students in other countries. At the finals level of the Google Science Fair finalists do meet, but the vast majority of participants do not enjoy this face-to-face opportunity; and even when the handful of finalists meet, they still are not working together in any way on a science project or problem.

In these two examples, International Baccalaureate and Google Science Fair, large numbers of schools, teachers, and students are involved, but as few as two classrooms, each in a different country, could be functioning at the aware stage, if students in both classrooms are aware they are doing the same activities in both classrooms. Such a situation might be rare, but theoretically possible. The point is large numbers of students need not be involved for classes to be functioning at the aware level.

One could reason, at this stage, students are no more interdependent with students from other countries than are students in the isolated stage. However, in the aware stage students in one country are dependent on having students participating in one or more other countries in order for the awareness to occur. Thus, there is interdependence, albeit at a low level, between students in one country and students in another.

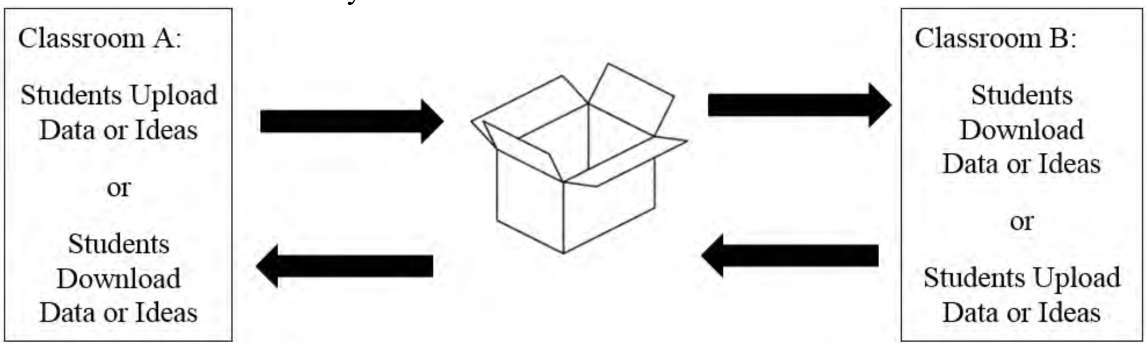
Before considering additional stages in the continuum, it needs to be recognized that each successive stage in the continuum, starting with the next stage, possesses its own unique characteristics as well as characteristics, somewhat modified, of the preceding stage. Thus, for example, a classroom operating at the next stage called share possesses the unique characteristics of the share stage plus the awareness of a classroom in another country part of the preceding aware stage.

Stage 2: Share

At this stage in the continuum, students begin to interact with students across borders. To highlight that transition the stages' one-word labels change from adjectives (i.e., isolated and aware in stages 0 and 1) to verbs (i.e., share, cooperate, and collaborate in stages 2, 3, and 4) to demonstrate students are becoming more internationally active.

At this stage 2, students share information across borders in the form of data or ideas by either uploading data or ideas to a database that can be thought of as a box into which data or ideas are placed or from which ideas or data can be downloaded. Also, students may both upload and download the data or ideas. Although students are sharing data or ideas across borders, the sharing passes through an intermediary, as shown in Figure 3 as a box. Thus, students do not experience direct contact with specific other students. Metaphorically, a curtain hides students in the two or more countries from each other.

Figure 3. Depiction of the Share Stage in Which Data and/or Ideas Are Either Uploaded to and/or Downloaded From a Box by Students in Two or More Countries



The clearest opportunity for teachers to have their students share information in the form of data or ideas with students from other countries can be found in citizen science (Cooper, 2016). Using scistarter.org, teachers can search for projects appropriate for their students. For example, searching for weather-related projects, which could be undertaken at school, might lead a teacher to *I See Change* (https://www.iseechange.org/) in which students from around the world can participate. Students can upload data such as first sightings of a seasonal change that then can be connected to NASA satellite information; and that data set plus data from other observers can be downloaded from around the world to determine, in this case, global patterns in seasonal change.

GLOBE (Global Learning and Observations to Benefit the Environment), one of the oldest citizen science projects for students, began in 1995 and since then has involved schools from over 120 countries on all continents except Antarctica (GLOBE, n.d.). Students, whose teachers have been trained to follow GLOBE protocols, upload data about water, soil, atmosphere, and plant cover; then any student anywhere can download those data, for example, to compare a desert ecosystem with the ecosystem where they are located.

Distinguishing Cooperative and Collaborative Learning

Some authors use cooperative learning and collaborative learning as interchangeable synonyms while others make distinctions. Some authors make the same distinctions as other authors, but in other cases the two authors' distinctions are dissimilar. In all cases prior to the advent of the Internet that allows communication across classrooms, cooperative and collaborative learning were viewed as something that happens within classrooms. In contrast and in recognition of the Internet's impact on schooling, the students' global interdependence in science continuum focuses on cooperative or collaborative student interactions, as defined here, in two or more classrooms and pays no attention to activities among students within a single classroom.

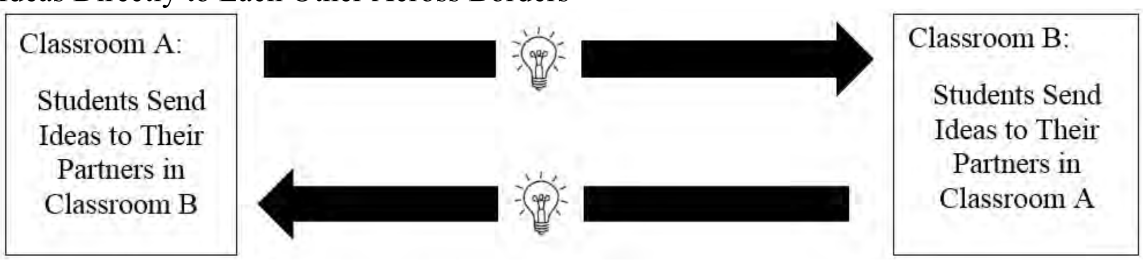
With roots back to the 19th century with educators like Parker and Dewey who were grounded on even earlier educators and theorists such as Rousseau, Pestalozzi, and Froebel (Cremin, 1964), cooperative learning gained contemporary prominence from Slavin (1980), the Johnson brothers (Johnson & Johnson, 1989), and others (e.g., Cohen, 1986). These authors focus on student activity within the classroom, looking at variables such as positive interdependence, face-to-face promotive interaction, and group processing (Johnson et al., 1991). Laal (2013) built a bridge from cooperative to collaborative learning by focusing on cooperative learning's positive interdependence as an underpinning of collaborative learning. In each of these instances of cooperative learning, the author tended to focus on the individual operating within the group. Stahl (2006) shifted the focus from the individual as part of a group to the group as a whole where individuals jointly made meaning, which became the unit of analysis.

As will be seen, the students' global interdependence in science continuum distinguishes between a stage called collaborate where students work as a group, in a manner informed by Stahl's group cognition (2006), to co-create ideas. In contract, the SGIS continuum defines its cooperate stage along the lines of Aronson et al.'s (1978) jigsaw classroom where students share, but do not co-create ideas.

Stage 3: Cooperate

In the SGIS continuum's cooperate stage, students share ideas across borders (See Figure 4) where ideas are depicted as lightbulbs and note the absence of the box shown in Figure 3.

Figure 4. Depiction of the Cooperate Stage in which Students in Two or More Countries Share Ideas Directly to Each Other Across Borders



As in the share stage, information is made available to others; but unlike the share stage, students in the cooperate stage are exchanging information directly, not through an intermediary, with specific other students. The share stage's metaphoric box does not operate in the cooperate stage as an intermediary to which students can upload and download data. Recalling the previously imagined students in different countries, in the share stage a curtain between the two students hides them from one another. However, in the cooperate stage that curtain is removed; and students communicate directly with each other.

An example of the SGIS continuum's cooperate stage can be found in the World MOON Project, described in its early configuration by Smith (2003) and in its current iteration at www.worldmoonproject.org. Students around the world observe the Moon and share their observations online directly with their international partners. After assembling and interpreting the lunar data, students identify a global pattern in the data (e.g., the Moon has the same shape for every observer on the same day; but students in the temperate latitudes of the Northern and Southern Hemispheres see the Moon illuminated on opposite sides [right or left] on the same day). Descriptions of and evidence for these patterns are exchanged between partner students; and finally, students, working separately from their global partners, figure out a cause for one of the identified patterns (For example, the changing shape of the illuminated portion of the Moon is caused by the shifting positioning of the Earth, Moon, and Sun as the Moon revolves around the Earth). Then they share their ideas about causation. In each of these cases, students on either side of the partnership create their own ideas that they share. There is no back-and-forth, give-and-take between partners to create ideas together.

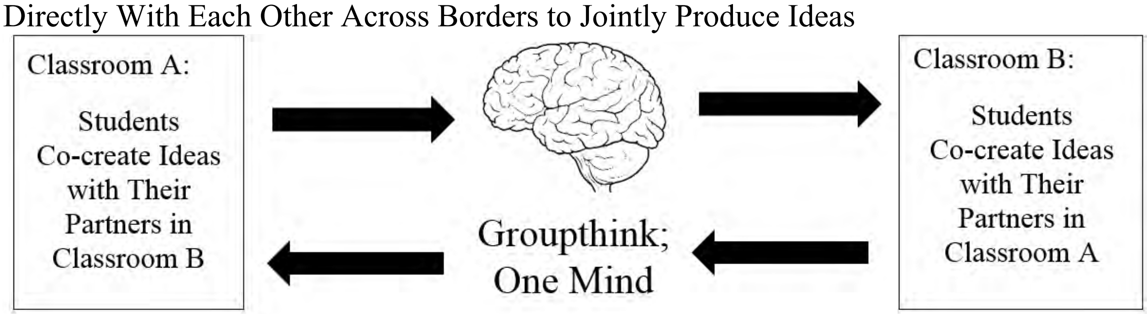
As an example of how the SGIS could be employed outside of science, preservice teacher education students in an American midwestern university studying multicultural education were placed in a pen-pal relationship with counterparts in a Turkish university (Lin, 2018). For 14 weeks the students exchanged information about their everyday lives in each country and the situation resulting from Syrian immigrants escaping their war-torn nation to bordering Turkey. In this case students were interacting directly with specific students in another country to exchange information, but not jointly solving any tasks presented to them other than to trade information. Thus, such an activity would be classified as cooperate, if the SGIS were modified to be used outside of science instruction.

Stage 4: Collaborate

In contrast to the SGIS continuum's cooperate stage where students share but do not co-create ideas, in the collaborate stage students across borders co-create ideas together. (See Figure 5 which depicts the meeting of the minds of students from two or more countries group-thinking together as one mind about some problem in order to produce a joint solution.) For example, the Centre for Global Education (http://www.tcge.ca) located in Edmonton, Alberta, Canada, hosts student forums that lead to position papers, group-authored by multiple students from several countries, on topics such as climate change, disease, or clean water.

As another example, students in Australia and the United States worked in teams of two from Australia and two from America to create an edible lunar vehicle (Davey et al., 2009). Working primarily asynchronously through blogs because of the time difference, but with two specially scheduled synchronous videoconference sessions, each team as a team had to design, build, test, and modify a vehicle of a certain size, suitable for lunar exploration, that was able to travel a set distance after rolling down a ramp and then be completely eaten by the builders. Two versions—one in each country—of the vehicle had to be built to match, so materials and building procedures had to be agreed on in order for identical vehicles to be built.

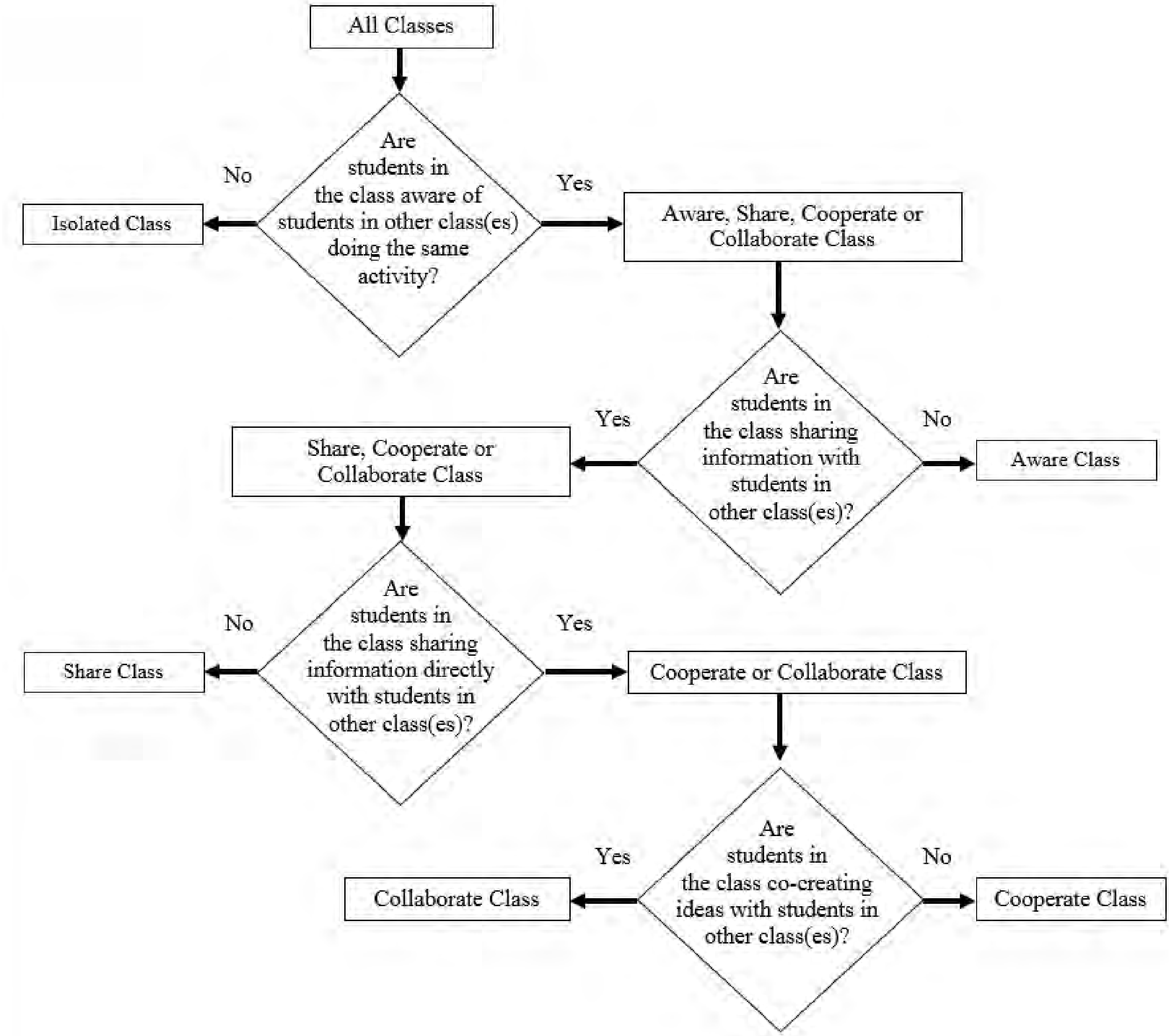
Figure 5. Depiction of the Collaborate Stage in which Students in Two or More Countries Work Directly With Each Other Across Borders to Jointly Produce Ideas



Classifying Global Education Activities According to the SGIS Continuum Stages

Throughout a school year, students in any classroom will be involved in a large number of different activities. At some times the classroom activities may be classified as being at the isolated stage of the SGIS continuum, but at other times that same class may function at the collaborate stage or any other stage. A dichotomous key can be used for this classification by asking about the classroom activities a series of four yes-no questions, as shown in Figure 6, which start at the top and continue back and forth to the bottom.

Figure 6. Dichotomous Key Used to Classify Classroom Global Activities



Note. Classify a class activity by starting at the top with the first question. Continue down until an answer to a question identifies the specific stage of the activity.

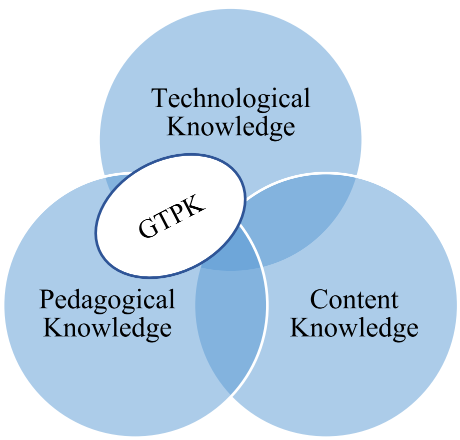
The first question at the top of the key asks, *are students in the class (being observed) aware of students in other classes (in other countries) doing the same activity*. If the answer is no (i.e., the students are not aware of students in other classes in other countries), then the class being observed is classified as an isolated class and the questioning can stop, since the class has been identified. However, if the answer is yes, then the activity being observed may be classified as being in the aware, share, cooperate, or collaborate stage. The next question, *are students sharing information with students in other classes (in other countries)*, allows the observer to distinguish between aware classes on the one hand versus share, cooperate, or collaborate classes on the other hand. From there, if necessary, the observer can continue to ask questions in the sequence shown in Figure 6 to distinguish among the share, cooperate, and collaborate categories.

Uses of the Students' Global Interdependence in Science Continuum

As mentioned, the SGIS continuum can be used by science education researchers or casual observers; and among the casual observers can be found preservice or in-service teachers, other educators such as principals or science specialists, parents, or the general public. Beyond these two broad groups, researchers in other areas of the curriculum could adapt the continuum to their subject areas. As alluded to previously, the continuum could be used to classify STEM's technology or engineering, as well as science, classroom activities; but the continuum could also be modified to become applicable to mathematics, language arts, or social studies classes and so forth. The SGIS continuum could also be used as a component of studies on topics such as social justice, curriculum, or student motivation.

If the students' global interdependence in science continuum is to be used in preservice teacher education or in-service teacher professional development to instruct educators to help their students become global collaborators, an additional circle, as shown in Figure 7 as GTPK for global technological pedagogical knowledge, must be added to the typical TPACK three circle Venn diagram depicting the overlap of technological, pedagogical, and content knowledge.

Figure 7. Relationship Showing Overlap of Technological, Pedagogical, and Content Knowledge With Offset GTPK



The new GTPK circle, was placed off center to show its primary overlap with technological and pedagogical knowledge. To adopt the continuum's share, cooperate, or collaborate stages, teachers will have to learn about appropriate technologies and their use in the classroom. For example, probably the easiest new skills to master can be found in citizen science in the continuum's share stage. At this stage teachers can use scistarter.org to find a citizen science project that is global in nature and fits the teacher's curriculum. Then the teacher alone or with their students can learn to use the project's software which usually is user friendly. On the pedagogical side of the ledger, if a teacher already employs project-based learning, the citizen science project will fit more easily in the teacher's skill set. However, if project-based learning is foreign to the teacher, then the teacher will have to learn how to incorporate a citizen science project into their teaching.

Learning to engage students in either the cooperate or collaborate stages requires a three-part process (or a 4-part process, if project-based learning is not already a part of the teacher's repertoire). Since teaching at the cooperate or collaborate stage requires students to work with students from another country, teachers will need skills for teaching students to work with students from other cultures. Secondly, teachers must learn how to make contacts with like-minded teachers across borders.

Teachers can work informally with intermediaries such as their acquaintances overseas, community groups such as Rotary International, or students' families; and some schools have school partners in other countries. However, lacking these informal channels, teachers may join a brokering agency that already exists, if their activities fit the teacher's curriculum. Previously the global student conferences sponsored by the Centre for Global Education (http://www.tcge.ca) were described. For over 30 years the International Education and Resource Network (n.d.), better known as iEARN, has helped teachers around the world collaborate for students to learn about a variety of topics.

Thirdly, teachers need to develop skills to have their students use a variety of available technology programs compatible with school policy, consistent with student abilities, and appropriate for the project to be undertaken. Google Hangouts (https://hangouts.google.com/) and Skype (https://www.skype.com/en/) are two programs for synchronous conversations among students; but often the timing is such that asynchronous communication through vehicles such as a podcast or videocast is needed.

Relationship of the Students' Global Interdependence in Science Continuum and 21st Century Skills

The creation, nearly two decades ago, of the Partnership for 21st Century Skills (now Learning), frequently known as P21, added voice to the advocacy for schools to teach so-called *soft skills* such as critical thinking, creativity, communication, and collaboration that together have been called the 4C's (P21 Partnership for 21st Century Learning, 2015). Further, P21 proposed five 21st Century Themes that included four literacies—civic, financial, health and environmental--along with global awareness.

Representative of many voices have called for schools to produce college and career ready graduates. The U. S. Department of Labor wrote:

> Two conditions that arose in the last quarter of the 20th Century have changed the terms of our young people's entry into the world of work: the globalization of commerce and industry and the explosive growth of technology on the job. (1991, p. 6).

While global collaborative science education is not a panacea, it can contribute significantly to the development of students' communication and (global) collaboration skills, as shown in Figure 8, and can serve as a platform for the other two C's, teaching critical thinking and creativity.

Thinking about how these 21st Century skills, including communication and collaboration shown in Figure 8, and P21's global awareness theme play out in the science education arena, examples in America's Next Generation Science Standards of how global topics enter the curriculum have already been pointed out. Kivunja (2015) showed how the 4C's can be tied together to a frequently used science teaching approach referred to as the 5E's (Engage, Explore, Explain, Elaborate and Evaluate or rephrased as nouns: Engagement, Exploration, Explanation, Elaboration, and Evaluation) described by Bybee et al. (2006) based on numerous education theorists such as Bruner (1960), Karplus (1977), and Vygotsky (1978). The 5E model is broadly used in science instruction including programs such as Full Option Science System (https://www.fossweb.com), Smithsonian Science for The Classroom (Smithsonian Science Education Center (https://ssec.si.edu/), STEMscopes (https://www.stemscopes.com), and others.

Figure 8. Intersection of 21st Century Skills and Students' Global Interdependence in Science Stages

21st Century Skills[a]	Students' Global Interdependence in Science Stages[b]		
	Share	**Cooperate**	**Collaborate**
Communications	When students upload data or ideas, they are communicating in one direction to a faceless audience *out there*. Since they receive no direct feedback from their audience, they receive no indication of the clarity of their message, so classroom teachers or fellow students need to provide assistance. However, feeling an obligation to others to provide appropriate communication, students are motivated to communicate well.	Students must be careful to write or speak clearly and completely so the recipients of their message clearly understand the message being conveyed. The message sent back from the partner, by inference, may provide feedback about the clarity of the original message. Students need to be aware of cross-cultural communication issues.	Students must be careful to write or speak clearly and completely so the recipients of their message clearly understand the message being conveyed. Since students on both sides of the project are co-creating a solution, (a) that solution needs to be mutually agreed upon and (b) each student receives the same kind of feedback that occurs in face-to-face communication. Students need to be sensitive to needs of cross-cultural communication.
Collaboration	Communication for each student is one-sided with no collaboration with any other specific student. That is, students upload data and ideas into a dbase to possibly be downloaded by another student.	Students share their own data and ideas with specific other students; but since there is no co-creation of ideas, there is no collaboration beyond trading data and ideas among the students.	Since a product is produced jointly by students co-creating the product, there must be a high degree of collaboration among partners.

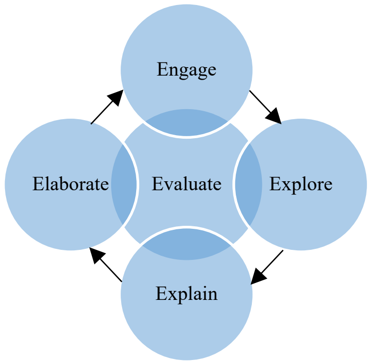
[a] Critical thinking and creativity from the 4C's are not included, since the share, cooperate, or collaborate activities may, but do not necessarily, address critical thinking or creativity.

[b] The isolated and aware stages of the students' global interdependence in science continuum are not included, since students may, but do not necessarily address any of the 4C's (critical thinking, creativity, communications, and collaboration) per *se in those two stages.*

Instruction following the 5E model as depicted in Figure 9 begins with capturing the students' attention on the topic (engagement) and follows in order with allowing students to actively investigate the topic (exploration), students drawing conclusions based on their investigation (explanation), and then learning more about the topic (elaboration) with some kind of formative or summative evaluation occurring in each of the other four E's.

Kivunja (2015) described how each of the 4C's could be incorporated into each of the 5E's. For example, creative thinking could appear in the engagement by presenting perplexing problems to students requiring them to think about what they know already and what they need to find out in order to solve the mystery. The students could work on their problem solving in teams that require the students to collaborate on collecting data (exploration) and develop a causal solution for the perplexing problem (explanation). Science is replete with problems that can pique student interest and, via the 5E approach, scaffold students' thinking about the phenomena they have viewed.

Figure 9. Bybee et al.'s 5E Model of Science Instruction



Summary

Various groups and societies have called for global education in various forms in schooling with attention to the outcomes described in the form of goals, principles, or standards. Instead of looking at the curriculum, in this article, attention focuses on the student and the global interdependence of students during instruction. The driving question has been *What is the student doing interdependently with one or more students from another country or countries during school science instruction*? A five-stage continuum from no interdependence to complete interdependence has been described. The continuum may be used by researchers and others to better understand global science instruction; but additionally the model presented here can be adapted for use in other disciplines, and the various levels of interdependence described by the continuum can support science instruction to address the learning of the 4C's: critical thinking, collaboration, communication, and creativity.

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