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Using Knowledge Forum to Support the Development of STEAM Literacies

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Abstract: Over the last decade, there has been growing interest in Science, Technology, Engineering, Arts, and Math (STEAM) education to promote creativity and design thinking in schools. Knowledge Building, which engages students in sustained, interdisciplinary work with ideas, represents one pedagogical approach to achieve these goals, while Knowledge Forum technology facilitates the implementation of STEAM education in classrooms. This study explores the simultaneous development of 8- and 9-year-old's scientific literacy, graphical literacy, and mathematical literacy in Knowledge Forum. Between fall and winter term, a grade 3 class studied growth and changes in plants. Qualitative analyses on student work in Knowledge Forum reveal increasingly proficient use of expert vocabulary to explain scientific phenomena, as well as productive use of increasingly complex graphical and mathematical representations to explore socio-scientific issues. Study implications are discussed within the context of STEAM education and assessment of 21st Century competencies.

Keywords: Knowledge Forum, STEAM, scientific literacy, graphical literacy, mathematical literacy

1. Introduction

Creativity is becoming widely recognized as one of the most important competencies of the 21st century (e.g., OECD, 2018; World Economic Forum, 2016). Given the growing need to build collective capacity for creativity, educators and policymakers have been advocating to expand Science, Technology, Engineering, and Math (STEM) education into Science, Technology, Engineering, Arts, and Math (STEAM) education (Butler & Luke, 2012; Liao, 2016). STEAM education is defined as:

> "The inclusion of the liberal arts and humanities in STEM education; some STEAM conceptions simply use the 'A' to indicate a fifth discipline area— namely, arts and humanities, with sub-disciplines as have historically existed for STEM areas; however, an alternative conception is to integrate liberal arts and humanities into STEM education as an expansion of an expanded crossdisciplinary approach being advocated for STEM education." (Spector, 2015, p. 5)

One of the core aims of STEAM education is to make design thinking an explicit process of knowing and learning to facilitate the integration of the disciplines (Bequette & Bequette, 2012) and the development of students' creativity (Maeda, 2012; Henriksen, 2014). This perspective is in line with Knowledge Building (Scardamalia & Bereiter, 2014), a pedagogical approach that engages students in sustained creative work with ideas. During Knowledge Building, students work together to tackle complex, real-world problems. They generate theories and hypotheses, critique explanations, and examine multiple sources of evidence from different perspectives before refining their theories to advance collective understanding. An online platform called Knowledge Forum (Scardamalia, 2017) is commonly used as the community design space for students to share ideas, build on ideas, take them apart, and reorganize them in more conceptually coherent ways. Past studies provide evidence that the integration of Knowledge Forum into daily classroom practices significantly enhances students' scientific literacy (Sun & Zhang, 2010), mathematical literacy (Moss & Beatty, 2010), and graphical literacy (Gan, Scardamalia, Hong, & Zhang, 2010).

Given the interdisciplinary nature of Knowledge Building and Knowledge Forum, it follows that Knowledge Forum is a promising technology for engaging students in STEAM-related activities. This study explores how students can simultaneously develop scientific literacy, graphical literacy, and

mathematical literacy through sustained collaborative work with ideas in Knowledge Forum. Over the span of eight months, 22 students in a grade 3 class in Toronto, Canada studied growth and changes in plants (Ontario Ministry of Education, 2007). Students wrote over 400 notes across 9 views in Knowledge Forum on topics such as, “Do Plants Grow”, “Plant Roots”, “Worms and Leaves”, “The Bean Video”, “Plant Experiments”, “Photosynthesis”, “Photosynthesis Seen from Space”, and “Travelling Inside a Leaf”. On average, each student wrote 20 notes, read 62 notes, and created 4 drawings, suggesting they were actively engaged in multimedia-rich activities on Knowledge Forum. In the sections below, we traced qualitative shifts in students’ contribution patterns across the three different literacies between the fall term and the winter term.

2. Scientific Literacy

Scientific literacy is “the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen” (OECD, 2016). This includes the ability to explain phenomena, design experiments, and interpret data. In Knowledge Forum, students can contribute their ideas as notes to be further built on by their peers. The note editor includes a textbox, epistemic markers, and keyword tags (see Table 1) to facilitate the learning of new concepts and ideas. In this section, the analysis will focus on shifts in students’ vocabulary use in their notes as they explain the scientific phenomenon of photosynthesis.

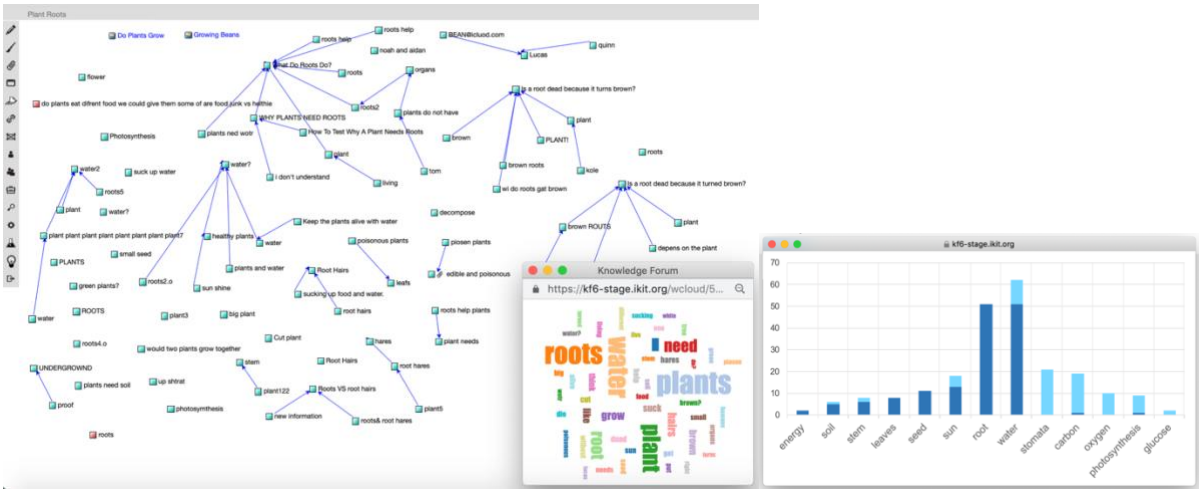

Figure 1. Knowledge Forum view and analytic tools, Word Cloud (left), Lexical Analysis (right).

Figure 1 shows one of the initial views on plants and the word cloud (left) associated with that view. Table 1 (top row) shows examples of students’ notes when they were sharing questions and theories of how plants grow and change. Intuitively, students were able to identify key characteristics of the environment, such as “water”, “sun”, and “soil”, as well as key characteristics of plants, including “stem”, “leaves”, and “roots” that play an important role in photosynthesis. After designing experiments and watching videos about photosynthesis in the fall term, students became more familiar with the process of photosynthesis and started adopting more expert vocabulary in the winter term. Table 1 (bottom row) shows examples of students’ notes when they were discussing the importance of “stomata” in photosynthesis and how it controls the flow of “oxygen” and “carbon dioxide” between plants and their environment. The lexical tool in Figure 1 (right) shows a drastic shift in students’ vocabulary use between fall term (dark blue) and winter term (light blue). Whereas in the fall term, students mainly used “water”, “root”, “sun”, “seeds”, “leaves”, “stem”, and “soil” to describe the process of photosynthesis, in the winter term, students mainly used “stomata”, “carbon”, “oxygen”, “water”, “sun”, and “glucose” to describe the process of photosynthesis. It can be seen that as students gained a deeper understanding of photosynthesis, their vocabulary became more precise and scientific.

Table 1

Examples of Students' Notes from Fall Term and Winter Term

View	Note
Do Plants Grow	[My theory]: All plants grow cause they have a **stem** and if you break the **stem** and do nothing with it, it dies. [My theory]: They grow because of **water** and **sun**. [I wonder]: how do plants survive with only **water** and **soil**. [My theory]: is a plant needs **roots** to survive. [My theory]: is that not all plants grow because if the plant has no **leaves** that can cause them not to grow.
Photosynthesis	[A new word I learned]: was that **stomata** is the thing that lets all **water** and **carbon** dioxide in and lets out **oxygen.** [A new fact I learned]: is that a plant needs **water** and **sunlight**. [My improved theory is]: that the **sun** helps the plant breath. [I still need to understand]: how the **stem** sucks up **water**? [My theory]: is that there is lots of stuff in a plant like **stomata** and **glucose** and **oxygen** and alot more.

3. Graphical Literacy

Graphical literacy is "the ability to construct meaning from visual experiences, organize information based on the composition of images, and use symbols to express meaning" (Nelson, 2004). This includes the ability to learn, think, and communicate with non-textual representations. In Knowledge Forum, students can contribute their ideas as drawings to be further built on by their peers. The drawing editor includes colours, lines, shapes, symbols, attachments, and text to facilitate the creation of complex, multi-layered graphical representations. In this section, the analysis will focus on students' different uses of drawings to advance the community discourse on photosynthesis.

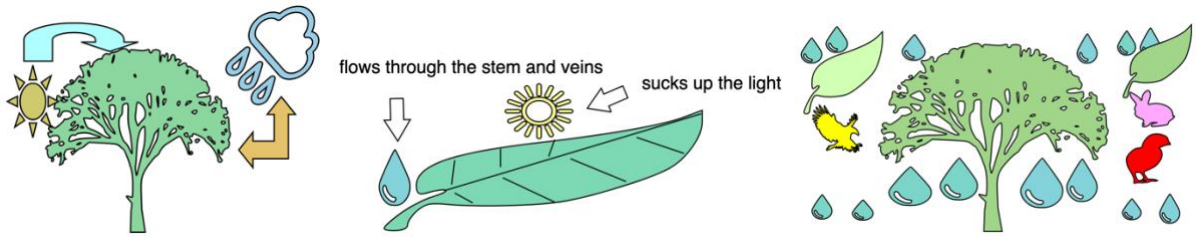

Figure 2. Three different graphical representations related to photosynthesis.

In the winter term, students were introduced to the drawing tool to elaborate on their understanding of photosynthesis. Figure 2 shows three drawings by three different students on the process of photosynthesis that were created a few weeks apart from one another. It can be seen that students used colours, symbols, arrows, and labels as means to graphically represent their ideas. The first drawing shows photosynthesis as a cycle between the sun, water, and trees, thus reinforcing their prior understanding that plants need sun and water to grow. The second drawing shows photosynthesis at a micro-level, highlighting the role of different parts of the leaf (i.e., stem, veins, stomata). The student also added their new understanding that roots and stems act as the transport system in plants – a new fact they learned from watching a video. The third drawing shows photosynthesis at a macro-level, highlighting the relations between water, plants, and animals in ecosystems. After learning about the process of photosynthesis, students came to understand the symbiotic relationship between humans and plants (i.e., humans depend on plants for oxygen and plants depend on humans for carbon dioxide). The last drawing led students to wonder whether photosynthesis is as important for animals as it is for humans. Table 2 shows examples of students' notes as they debated this controversial issue. It can be

seen that some students became very passionate about the issue, instilling a sense of environmental stewardship in the entire community as the discussion shifted organically toward how they could save living things on the planet from the perils of climate change.

Table 2

Examples of Students' Notes from Winter Term

View	Note
Photosynthesis Seen from Space	Is photosynthesis important for animals too? I think so because humans are animals. Birds, animals, and insects help in the cycle of life!!!!!!!! Do you think that animals could live with little carbon? BUILDINGS ARE KILLING PLANTS AND THERE ARE LESS AND LESS ON EARTH… BUILDINGS ARE ALSO KLLING ANIMALS AND WITHOUT PLANTS ANIMALS CAN'T LIVE AND ALSO WITHOUT PLANTS THERE WILL BE NO PHOTOSYNTHESIS AND WE WILL DIE WITH NO AIR.

4. Mathematical Literacy

Mathematical literacy is the ability to "formulate, employ, and interpret mathematics in a variety of contexts… [This] includes making mathematical deductions and applying mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena" (OECD, 2016). Because there is no feature in Knowledge Forum designed specifically to support mathematical literacy, students were not expected to share their understanding through numbers, formulae, and mathematical expressions. Surprisingly, a few students did. In this section, the analysis will focus on students' uses of numbers and charts to enrich their collective understanding on photosynthesis.

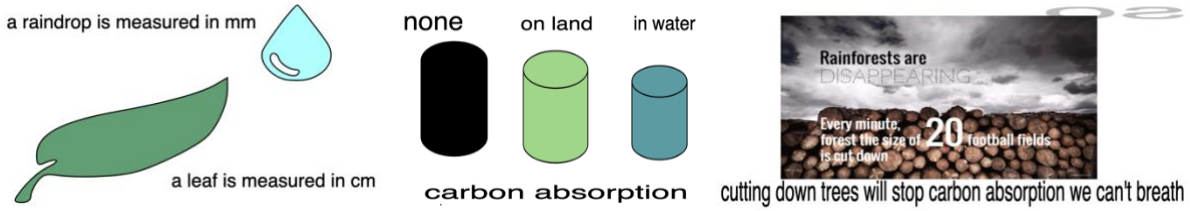

Figure 3. Three different mathematical representations related to photosynthesis.

After studying the process of photosynthesis in the fall, students worked in new Knowledge Forum views in the winter to explore issues at a micro-level (Travelling Inside a Leaf) or at a macro-level (Photosynthesis Seen from Space). In the view, Travelling Inside a Leaf, students watched a video animation on the cellular structures inside leaves. Notes and drawings in this view explored the size of cells and how energy is created in the leaf. Figure 3 (left) shows a comparison between the size of a raindrop and the size of a leaf, as well as their respective unit of measurement. In the view, Photosynthesis Seen from Space, students watched a time-lapse video of carbon absorption in different places in the world over the span of a year. Notes and drawings in this view explored similarities and differences across different countries, as well as changes in the amount of carbon absorption during different seasons of the year. Figure 3 (center) shows a comparison between the proportional amount of carbon absorption on earth's land water, and places where there was no carbon absorption at all. This drawing led students to hypothesize that places where there was little or no carbon absorption had higher levels of pollution. Table 3 shows examples of students' notes as they discussed issues surrounding carbon absorption and carbon emissions (i.e., pollution) on earth. Figure 3 (right) shows an image a student found that features a statistic on deforestation. The student further adds their theory that large-scale deforestation will disrupt the naturally occurring carbon absorption patterns on earth. It can

be seen that students used mathematical concepts to effectively describe, explain, and predict scientific phenomena. Furthermore, students were aware of the unit of analysis across the two topics – Travelling Inside a Leaf and Photosynthesis Seen from Space – which spanned from micrometers inside a cell to kilometres around the globe.

Table 3

Examples of Students' Notes from Winter Term

View	Note
Photosynthesis Seen from Space	[My theory]: is that there are a lot of trees and plants in the green and in the dark part there is less trees and plants. I think that the colours represent different environments. Like light green… represents land that has been not in pollution... [and] dark green represents land that has been in pollution. The equator has a lot of photosynthesis. North America has none… - barely any in Antartica, summer or winter… Australia there is less photosynthesis in Australia due to ground pollution. [My theory]: pollution is terrible because of pollution animals and plants are dying. Using plastic is water pollution. Cars make air pollution that's killing the environment.

5. Discussion

Over the span of 8 months, students worked collaboratively on Knowledge Forum to advance their understanding of growth and changes in plants. They shared their initial ideas and theories through notes, reflected on their peers' ideas and new information from authoritative sources (e.g., videos), before building on with new notes and new drawings. They broke down key ideas from videos into notes, drawings, and graphs, which helped deepen collective understanding and spark new cycles of theory development. To summarize, students wrote notes about the process of photosynthesis (e.g., key characteristics of plants, the role of oxygen and carbon dioxide) and climate change (e.g., rates of carbon absorption/emission, the effects of deforestation and pollution). They created drawings about the process of photosynthesis (e.g., the role of sun and water, anatomy of a leaf, plant-animal relations in ecosystems). They even created drawings to show proportional relations (e.g., size of raindrop vs. leaf, carbon absorption on land vs. water). Knowledge Forum provided flexible and dynamic supports for students to engage in these rich STEAM-related activities, thus promoting the simultaneous development of their scientific literacy, graphical literacy, and mathematical literacy. Between fall term and winter term, students demonstrated an increasing proficiency with expert vocabulary to explain photosynthesis, and they created increasingly complex graphical and mathematical representations to explore socioscientific issues, such as air/water pollution, deforestation, and climate change.

It is interesting to note that after the teacher invited students to shift from textual to graphical representation of their ideas in the winter term, students themselves initiated the subsequent shift from graphical to mathematical representation of their ideas. Put differently, as students' ideas evolved and matured, so did their medium of expression regardless of content area. For this reason, we believe that our study reinforces the notion that "graphical literacy and deep understanding are mutually reinforcing, with graphical literacy serving as a powerful thinking tool across content areas" (Gan, Scardamalia, Hong, & Zhang, 2010). Our study also adds that engaging students in STEAM-related activities in Knowledge Forum can serve as a powerful mechanism to sustain ever-deepening, creative, collaborative work with ideas.

5.1 Study Implications

While creativity development may be a top priority in 21st century education, it is equally important to ensure that students develop the foundations of scientific literacy, graphical literacy, and mathematical literacy throughout their schooling experiences. The design challenge for teachers is to create an interdisciplinary space that weaves together Science, Technology, Engineering, Arts, and Math in a

meaningful and authentic way for students. Our study suggests that with appropriate technological supports, students themselves can also be co-designers of STEAM-related activities in the classroom. Students as young as 8 years of age are able to move seamlessly across the disciplines when they are engaged in authentic knowledge work, thus reinforcing the need for interdisciplinary assessments in STEAM education. Liao (2016) claims that STEAM education "affirms the process of creative production, utilizes the creative process to acquire knowledge, and teaches 21st-century skills". Future studies should explore the development of new features in Knowledge Forum to expand possibilities for creative production, such as a video component (e.g., slideshow, animation, annotation) in the drawing tool, and a mathematical functions component (e.g., algebraic equations, graphing capabilities) in the note editor. For example, students in our class would have enjoyed creating videos to illustrate the life cycle of a plant and/or creating graphs to compare the levels of carbon emission by country. Such rich multimedia-rich activities have the potential to further enhance their Knowledge Building. We believe that to be active citizens thriving in 21st century societies, students must harness their creativity to not only acquire knowledge, but also to create knowledge for public good.

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