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RESEARCH REPORT

Journal of Research in STEM Education
Real STEM: An Interdisciplinary STEM Program

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Abstract: *The integration of STEM programs within the educational framework through the establishment of STEM-designated schools and academic/career pathways is a national trend in the United States. The goal of implementing STEM in grade 6 to 12 schools is to prepare students for the demands of the 21st century, while addressing future workforce needs. Often, however, the STEM disciplines are taught within silos independent of each other. Students miss the opportunity to participate in the interrelationship between the STEM disciplines, resulting in missed opportunities to build critical reasoning skills. The Real STEM project focused on the development of interdisciplinary STEM experiences for students. The project was characterized by sustained professional development which was job-embedded and competency-based, and focused on the development of five STEM reasoning abilities within real-world contexts. To accomplish this we promoted inclusion of tasks that drew on multiple STEM disciplines, embraced the use of authentic teaching strategies, and supported development of collaboration through interdisciplinary STEM professional learning communities within the school and STEM experts from the community. The four tenets of the Real STEM project are presented, research on impact on teacher practice is provided, and school and teacher takeaways are discussed.*

Keywords: Interdisciplinary STEM, authentic teaching, collaboration, reasoning

Introduction

When teaching science, one of the major challenges faced by teachers is helping their students make connections between the science concepts they learn in different disciplines and how these concepts can help them explain natural phenomena that occur around them. Teachers understand the need to trigger students' curiosity and take into consideration their interests, especially when it comes to presenting subjects that seem irrelevant to them (Darby-Hobbs, 2013). Students may learn about fundamental principles; however, they often cannot understand how they are connected to the world around them or their application in explaining different phenomena and observations. Despite the fact that in many countries, several studies have shown students' views on science and technology to be quite positive, this has not yet reflected in their views on school science education (Jenkins & Pell 2006). This could also be related to the fact that teachers especially in primary education often follow a pedagogical approach that focuses on them conveying knowledge to students, rather than having students participate actively in the learning process (Fensham 2004). This teacher-centered science teaching approach that is deployed by many teachers often leaves students with a miscellany of facts, no sense of the big idea of why it matters, and the conception that science is a monolithic body of unquestioned and unequivocal knowledge (Osborne 2011). This is possibly one of the reasons why many studies show that pupils perceive school science as lacking relevance and it is often described as, abstract and theoretical. In order to

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tackle this problem and increase students' interest in science, many scholars propose the connection between formal science education and students' out-of-school experiences (Stuckey, Hofstein, Mamlok-Naaman, and Eilks 2013). Introducing an interdisciplinary organization scheme that allows students to link the concepts they learn in different science classes to a set of fundamental concepts and key principles, could help them build a more meaningful knowledge structure and increase their knowledge retention. Understanding the connection between science concepts and better understanding of fundamental and secondary principles might enable students to make better use of them when it comes to explaining phenomena in the world around them and thus find meaning in them. Increasing students' ability to explain phenomena and use the knowledge they have acquired could also play a role in increasing their appreciation and interest towards science.

At the same time, inquiry-based learning, which is a student-centered learning approach is gaining popularity among teaching communities all over the world, as many studies report its effectiveness (Ryan, 2009; Minner, Levy and Century 2010). Inquiry-based learning aspires to engage students in an authentic scientific discovery process. Such active learning strategies have proved to be among the most promising, when it comes to increasing students' learning (Froyd 2008). From a pedagogical perspective, the complex scientific process is divided into smaller, logically connected units that guide students and draw their attention to important features of scientific thinking (Pedaste et al. 2015). However, the overcrowded school curricula of many countries may make its application very limited or practically impossible. Dense curricula can potentially create a bottleneck in the application of inquiry learning and eventually discourage teachers from using it, despite its potential in increasing the changes of meaningful learning episodes for students.

In addition, as Cimer (2007) stated, meaningful learning occurs as students consciously and explicitly link their new knowledge to an existing knowledge structure since the process of trying to understand a phenomenon or explain an observation usually starts by referring to or building on our existing knowledge and based on that, try to come up with an idea that might explain it. The traditional method of fragmented teaching deprives students of the opportunity to connect facts and observations and build upon their current knowledge in order to explain them. Thus, this method acts as a barrier, not only in building students' cognition, but also in developing their problem-solving skills. On the other hand, using an interdisciplinary organization scheme of science concepts to make such connections between concepts and science disciplines can promote interdisciplinary learning, help students link their new knowledge to an existing knowledge structure as mentioned above and enable them to decipher the importance of what they learn in science classes and why it matters.

Another problem that we often find in science education is that students usually forget a large proportion of what they have learned when it comes to pure knowledge delivery based solely on concepts and theories. This could be because the curricula are often overcrowded with unfamiliar terminology and laws; they leave little room for enjoyment, curiosity, and a search for meaning (Sjøberg 2002). Time constrains, which could stem from dense curricula, do not allow enough time for students to reflect on and process they have been taught (Faught et al. 2016). Moreover, overcrowded curricula allow very little time (if any) for students to absorb what they have learned and assess its importance (Osborne et al. 2001).

Furthermore, the pieces of knowledge that do remain are random aspects of the curriculum, which are not necessarily the most fundamental ones and frequently misplaced in terms of connections to natural phenomena and its practical effects. In fact, students often assess the importance of what they learn in school based on misleading criteria. For example, students may assess the significance of a subject based on criteria like the possibility of questions coming from that subject in an upcoming test or the length of time spent on it in class by the teacher and not on how fundamental the subject matter might be. Students' difficulty in assessing the importance of a piece of information, could also be due to the fact that, curricula do not often focus on the context and the connection between what is taught in the science class and the world. A context-based curriculum, however, could contribute not only in identifying the importance of what is learned, but also in improving students' interest and a positive attitude towards science in general and in particular disciplines, for example, chemistry (Mandler, Mamlok-Naaman, Blonder, Yayon, and Hofstein 2012).

An interdisciplinary organization scheme can act as a 'backbone structure' which comprises of fundamental concepts and principles that allows students to make easy connections between previous and new knowledge, as well as between science concepts taught and phenomena present in everyday life thus giving these concepts a relative context. It can also help teachers save time with overcrowded curricula creating collaboration opportunities across different subject domains where common concepts can be gathered and presented under a common framework. In order to meet the needs of students as effectively as possible, this backbone structure would have to be interdisciplinary, overarching all science disciplines, allowing students to understand that concepts in science are transdisciplinary and also across grade levels, are deployed to explain and make sense of the same thing; the world we live in. By going back to the same knowledge structure every time a new concept is introduced, students may find it easier to understand this new concept, thus making the learning process more efficient and less time-consuming. Additionally, this revisiting of the same knowledge structure and the connections between concepts can increase knowledge retention and potentially enable students to assess the importance of each concept based on more meaningful criteria like its role in understanding phenomena and its connection to fundamental principles.

Such a structure, being interdisciplinary, could also be the starting point in fostering the collaboration between teachers of different disciplines to use activities with their students that approach the same subject from different viewpoints. Such activities could ideally be designed using an inquiry approach, which is known to improve students' knowledge retention (Dresner, de Rivera, Fuccillo, and Chang 2014). The combination of an interdisciplinary learning context with the inquiry approach can potentially increase students' interest in science, and consequently their scientific discovery skills, as research shows that such skills are evolving continuously and are more likely to be improved, when motivation and interest in science is fostered (Keselman 2003). This interdisciplinary inquiry-based type of learning could also allow students to explore more in depth, the subjects at hand and gradually modify their understanding of science from a set of isolated disciplines which are about unrelated topics and concepts to a coherent and well-orchestrated mechanism for making sense of our world.

In a report published in 2010, a set of ten principles underpinning the science education of all students is presented based on the work of a group of scientists, engineers and science educators. According to this report, "students should be helped to develop 'big ideas of science' and about science that will enable them to understand the scientific aspects of the world around and make informed decisions about the applications of science." (Harlen 2009, p.4).

The "Big Ideas of Science" are a set of core ideas that connect phenomena and principles. They are reference points students can come back to in order to understand the relation between phenomena and principles. Grasping the big ideas enable learners to individually understand various aspects of the world around them, both the natural environment and that created through the application of science (Harlen, 2009). A big idea may be thought as a linchpin, one that is essential for understanding. Without grasping the big idea and using it to hold together related content of knowledge, we are left with bits and pieces of inert facts that cannot take us anywhere (Wiggins and McTighe, 2005).

We believe that a set of principles like the "Big Ideas of Science" could be the interdisciplinary organization scheme of science concepts discussed above, help tackle the problems mentioned earlier and help teachers change their teaching style towards a more interdisciplinary approach. Such a set of principles could play the role of the backbone structure of core science concepts, one that could be used by teachers and students as a reference point when teaching science across school grades and help students attach new pieces of knowledge to an existing knowledge structure. In this context, a "Big Ideas of Science" set could act as a compass for students towards understanding better, the significance of what they learn in school. In addition, keeping a constant cognitive reference point like the "Big Ideas of Science" set, and connecting each piece of new knowledge to it, may increase the chances of students to acquire a deeper understanding of facts and

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concepts and be able to retrieve and apply them in the future. By having a fixed reference point of fundamental ideas, students could also be in better position to evaluate what they learn at school, understand its importance and consequently find more meaning in it. Thus, although students still have to face overcrowded curricula they could have a guide that could help them distinguish the most fundamental concepts from secondary ones and understand how they are related and how they are used to explain phenomena in the world around them. Helping students identify and organize in their minds the concepts they learn, leads to a better ability of retrieving them and using them not only in the context of school but also in the outside world. A clearer idea of scientific concepts and how they are related can help students understand and identify more easily the laws and principles behind a natural phenomenon. In this sense, the "Big Ideas of Science" can be used not only as the means to connect science concepts in an interdisciplinary way, they could also facilitate students in connecting science concepts taught in school to the world around them by enabling them to better understand and identify the principles and laws behind natural phenomena.

Additionally, teachers of different science disciplines could potentially use a set of "Big Ideas of Science" in order to collaborate and find connections between the concepts they teach. By collaborating, making references to each other's classes and working together on interdisciplinary activities that focus on concepts connected through a big idea, teachers can increase students' interest and speed up the learning process as students recall existing knowledge, thus making it easier to understand and comprehend the new subject at hand. This way, there is more room for inquiry and students can have more time to spend on reflecting and processing new knowledge and make it part of a bigger knowledge structure.

With this in mind, we conducted a study to check whether a set, like the one introduced in Harlen's report could be used as an organization scheme that presents science concepts as a collection of related principles in a way that goes beyond the typical organization of science curricula and connects concepts in an interdisciplinary way. In this context we also made an effort to use the "Big Ideas of Science" as a tool to organize science educational content and resources, to present tools and activities in a coherent interdisciplinary format. Such a content organization could facilitate teachers in different science subject domains to identify common grounds on which they can build interdisciplinary activities. If used in class, it can also play the role of a reference point for students, one to which they can go back to every time they learn something new and through that establish connections with previous knowledge.

Our work was conducted within the framework of the "Go-Lab: Global Online Science Labs for Inquiry Learning at School" project (http://www.go-lab-project.eu/), which aimed to establish an online portal that facilitates the federation of existing virtual and remote science labs (De Jong et al. 2014; Govaerts et al. 2014). Our study's starting point was to examine whether a set like Harlen's "Big Ideas in Science Education" could be used in the Go-Lab repository (http://www.golabz.eu), as means of organizing online science labs and related activities.

The work presented in this paper is part of the work done in an effort to map and sample teachers and teacher trainers' understanding of the "Big Ideas of Science" concept, and investigate whether a set of such ideas could be helpful for them as a tool used to connect science concepts; especially concepts taught in different science subject domains and school grades. More specifically, in this paper we present the results from the second round of the validation process our team carried out in which we used the updated "Big Ideas of Science" set that was produced after concluding a first round of validation. We also present teachers' views on its use in teaching science in school. In addition, we also investigated teachers' views on the potential use of the "Big Ideas of Science" as the means of organizing educational content within the Go-Lab repository and through it promote interdisciplinary learning.

Methodology

Starting point and background work

The trigger for this work was the report already mentioned above edited by Wynne Harlen in 2010,

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the "Principles and Big Ideas in Science Education". We started by examining whether the ten principles set presented could be used to organize the content of the Go-Lab repository. To achieve this, we began by mapping the science vocabulary used in the Go-Lab repository to the ten big ideas mentioned in the report (Harlen, 2010).

This work was based on previous development implemented in the framework of the Open Discovery Project (ODS Project – D4.2). During this process, we found out that certain science terms from the science vocabulary, for example those that are related to quantum phenomena could not be clearly categorized under one from the current set of ten ideas. To this end, we decided to review several other similar sets from the bibliography (on science as a whole or on each science discipline separately) and to propose our own Go-Lab "Big Ideas of Science" set. The produced set was used to propose a methodology for organizing online labs and inquiry activities in the framework of the Go-Lab project (Zervas et al. 2014). Based on the definition used, the term "Big Ideas of Science" refers to "a set of cross-cutting scientific concepts that describe the world around us and allow us to conceive the connection between different natural phenomena". (Zervas, 2014; Dikke et al. 2014).

After the Go-Lab "Big Ideas of Science" set was produced, it was mapped again to the Go-Lab science vocabulary to make sure that it covered all science terms included. Once that was done, we conducted one validation round to record teachers' understanding of the concept, the degree to which they feel it can be used to connect science subjects as well as science subjects to phenomena met in everyday life and its usability as a recommendation system for organizing online science labs and related activities. The set was initially validated with science teachers of 93 European schools (Tsourlidaki, Zervas, Sotiriou, and Sampson 2015). In the sections below, we present the results from the second round of our validation process. For the second round of the validation process we used the same methodology and the updated "Big Ideas of Science" set (presented below) that was produced after concluding the first round of validation.

The bottom-up approach: teachers' views about the "Big Ideas of Science"

Study methodology

As mentioned earlier, the aim of our work was to sample the opinion of teachers and their trainers on the concept of the "Big Ideas of Science". Our research plan included questions that aimed to deduce how familiar our participants were with the term, the "Big Ideas of Science" prior to our workshop, their opinion on the Go-Lab "Big Ideas of Science" set and to what degree a set like that could be beneficial to them when teaching science to their students. In our set of questions, we also included some that aimed to record the degree to which teachers fill it is important to connect science concepts taught in different disciplines and different grades as well as how important it is for them to provide a context for their students by connecting what they learn in school to the world around them and phenomena from everyday life.

In order to increase participants' interest, we designed a hands-on and minds-on workshop, where participants were given the opportunity to reflect on the concept of the "Big Ideas of Science", what would constitute a set like that and collaborate with other teachers and their trainers to produce a set of "Big Ideas of Science" of their own. The validation workshops reported in this paper had three parts which were similar to the workshops reported in previous work (see Tsourlidaki et al. 2015):

Introductory part: In this part, participants were given a presentation on the concept of the "Big Ideas of Science". The presentation laid emphasis on the fact that students often forget most of the knowledge they have acquired at school, on the idea of connecting subjects taught in different science disciplines, as well as the need to design interdisciplinary activities for students and to have a reference point which students could use to make connections between different concepts and phenomena. It is worth noting that, although, the concept of the big ideas was discussed, no particular set was presented to the participants. In addition, prior to the presentation, a preliminary questionnaire was given to the participants to fill, so as to deduce the teachers' current knowledge on the "Big Ideas of Science" and their opinion about connecting what they teach in school with other subject domain, content from previous and coming grades as well as everyday life.

Brainstorming part: In this aspect, teachers were given time to reflect and think of concepts that in their opinion, should be involved in a "Big Ideas of Science" set. The question posed to them was: "If it was up to you to choose the eight or twelve (as many as you like) most important science concepts to teach your students; a set of concepts that your students would remember for the rest of their lives, what would these concepts be?" After writing down their ideas, participants were asked to share them with the rest of the team, everyone's ideas were reviewed and collaboratively, clusters of similar concepts and ideas were formed. Participants then formed groups; each group was invited to exchange ideas and put together a 'Big Idea' based on one cluster of concepts. The aim of this activity was to involve the teachers in a hands-on and minds-on activity that would motivate them in reflecting on the notion of the big ideas and think about what could constitute a big idea, based on their own opinion and experience. Thereafter, when we later on presented our own set of big ideas, the teachers could go through it and assess it more effectively based on their own ideas, thus, providing us with meaningful and concrete feedback.

Assessment part: Once the brainstorming part was completed, various groups presented their "Big Ideas" which were then discussed with the entire group. The Go-Lab set was then presented, and compared with the participants' Big Ideas. The presentation of the set also included a brief demonstration on how such a set could be used to connect different activities and online labs. Thus, give room and ideas for combining activities from different domains that fall under the same big idea. The use of such a set in the science classroom was then discussed, so as to determine to what degree teachers believe that this could be a useful tool for their students in understanding the connections between different phenomena and what they learn at school and their everyday life. The participants' opinions were also sampled with the use of a second questionnaire.

Results and findings

For our research, we conducted 19 workshops in different European countries, engaging 352 teachers in total. We conducted two rounds of the workshops. In the first round, we gathered input from 186 participants that participated in 11 of the workshops we carried out. After completing the first round of validation, we revisited our set of "Big Ideas of Science" and updated it based on the feedback received. While revising our set, we took into consideration the suggestions of teachers gathered from the questionnaires and in particular: a) their individual answers on the "Big Ideas of Science" according to them; b) the "Big Ideas of Science" produced by the brainstorming collaborative groups; c) their comments on the current Go-Lab set of "Big Ideas of Science"; d) the overall discussions during workshops.

In the second round of validation, which was comprised of 9 workshops, we followed the same methodology; the only difference being that we now used the updated version of our "Big Ideas of Science" set. In the second round, we involved another 166 participants. The results of our work are presented below.

Participants' profiles

Our workshops were conducted in Bulgaria, Cyprus, Greece, Italy, Portugal, Romania, Spain, the Netherlands, and UK. However, 6 out of the 19 workshops had international participants coming from several other countries. The total representation of participants comes from Austria, Belgium, Bulgaria, Croatia, Cyprus, Estonia, Germany, Greece, Hungary, Italy, The Netherlands, Portugal, Romania, Spain and UK. From our sample, 23.7% where trainers of science teachers. The rest of them where to their vast majority science teachers.

With regards to the general characteristics of our sample, we can see that there is a slight majority of women compared to men (61% Female, 39% Male). This is due to the fact that in some countries, like Italy for example, the vast majority of teachers who teach science are women. Aside that, majority of the teachers in our sample population are science teachers (94%) and 82% of them teach students between the ages of 9 and 18 years. In addition to this information, 63% of the teachers in our sample has at least a master's degree and 67% has more than 11 years of teaching experience, so they are considered to be quite experienced teachers.

Participants' familiarity with the concept "Big Ideas of Science"

At the beginning of every workshop, participants were invited to fill in a preliminary questionnaire so as to document whether they were familiar with the concept "Big Ideas of Science". As it was our aim to investigate whether a set of Big Ideas could be helpful for them to connect science concepts we also included questions about the degree to which they believe it is important to relate what they teach their students to concepts that students have learnt in the current or past grades, within the same or other science domains as well as to natural phenomena. These questions were included as our study was conducted under the framework of using of the "Big Ideas of Science" as an organization scheme for connecting science concepts from different grades and subject domains within an interdisciplinary framework. Thus, teachers' views on the importance of connecting science concepts in such a way (and how these views changed or not after participating in the workshop) was of great importance for our team.

This questionnaire was used in both rounds of workshops. Below, we present the results of our pre-workshop questionnaire for the entire sample population (352 questionnaires).

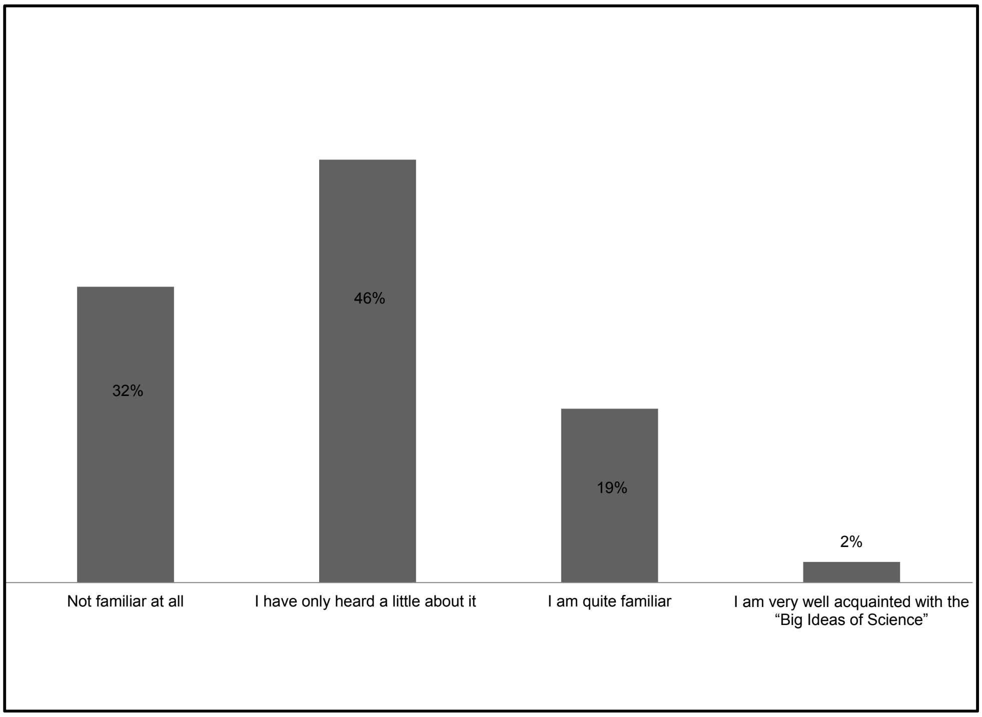

Table 1.

Teachers' opinion on the definition of the "Big Ideas of Science"

Which of the following definitions do you believe describes best the "Big Ideas of Science"?	*Number of responses*	*Percentage*

A. A set of ideas that briefly outline science's greatest achievements and discoveries.	48/352	14%
B. A set of cross-cutting scientific concepts that describe the world around us and allow us to conceive the connection between different natural phenomena.	207/352	59%
C. A set of concepts that outline how science works and what principles (ethical, social, economic and political implications) it is submitted to.	46/352	13%
D. A set of proposals that demonstrate to teachers how to teach science in the most successful and efficient way.	51/352	14%

As seen from the results above, although the majority of participants have enough experience in teaching science (15% of them have between 6 and 10 years of experience and 67% of teachers have more than 11 years' experience), 78% of them are basically not familiar with the concept of "Big Ideas of Science", so we know they do not use this approach in their everyday teaching. However, despite the high percentage of people who are not familiar with "Big Ideas of Science", 59% of them have selection B as their selected definition as presented in table 1 which is the definition of "Big Ideas of Science" given in this research (Dikke et al. 2014). This could indicate that, although, teachers are not very familiar with the term "Big Ideas of Science", it is still close to their understanding and they can relate with it and understand what it stands for.

As we consider the "Big Ideas of Science" to be a tool that could help students increase their ability to make connections between different science concepts and phenomena from our everyday life, the four remaining questions of the pre-workshop questionnaire aimed to record how often teachers tend to connect what they teach their students to everyday life and to other science subjects respectively, as well as to identify to what degree the teachers believe that these connections are important to be made in the science class. The results are presented in the figures below.

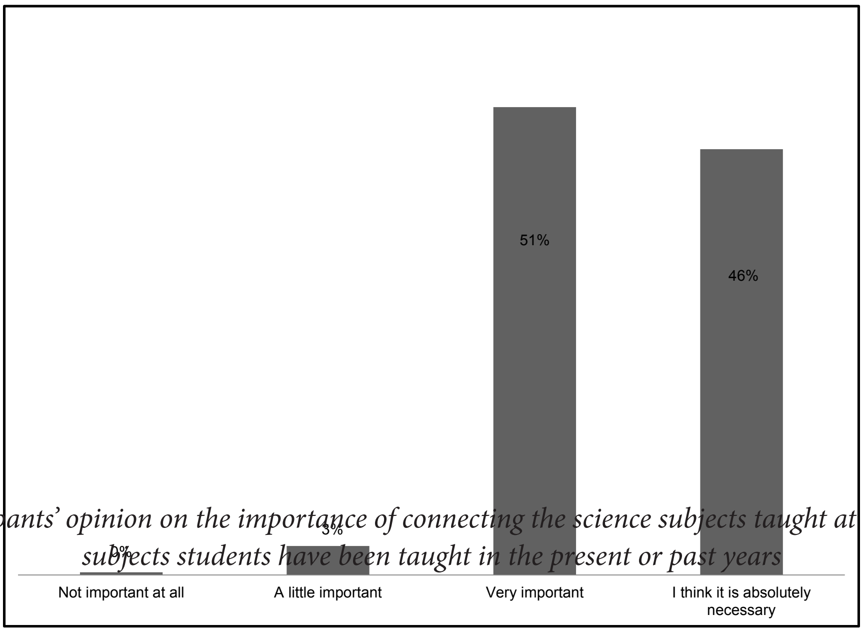

Figure 2. *Participants' opinion on the importance of connecting the science subjects taught at school with other subjects students have been taught in the present or past years*

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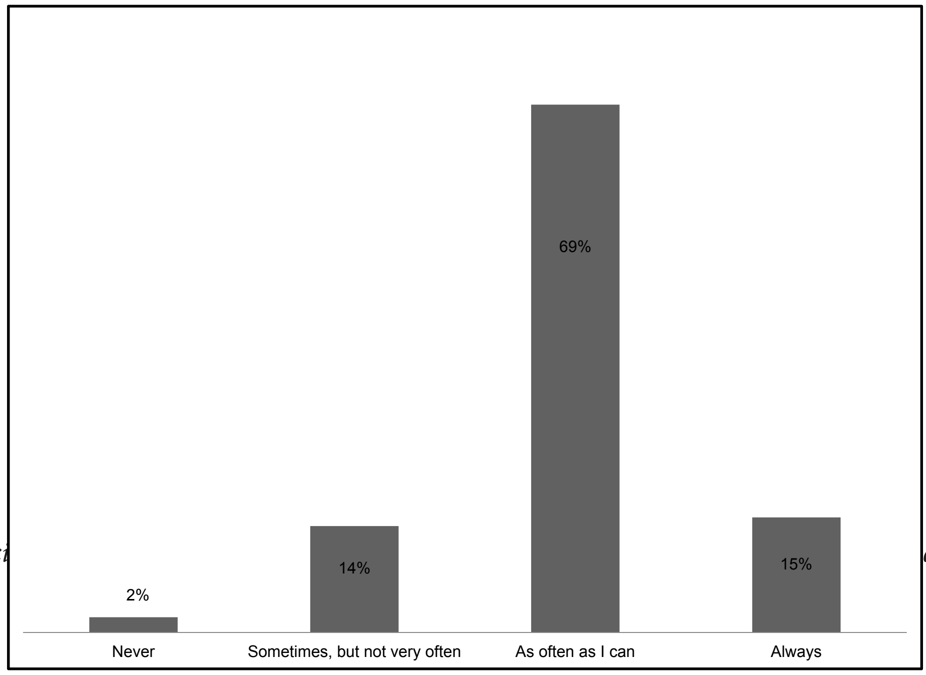

Figure 3. *Partici* … *ass with other*

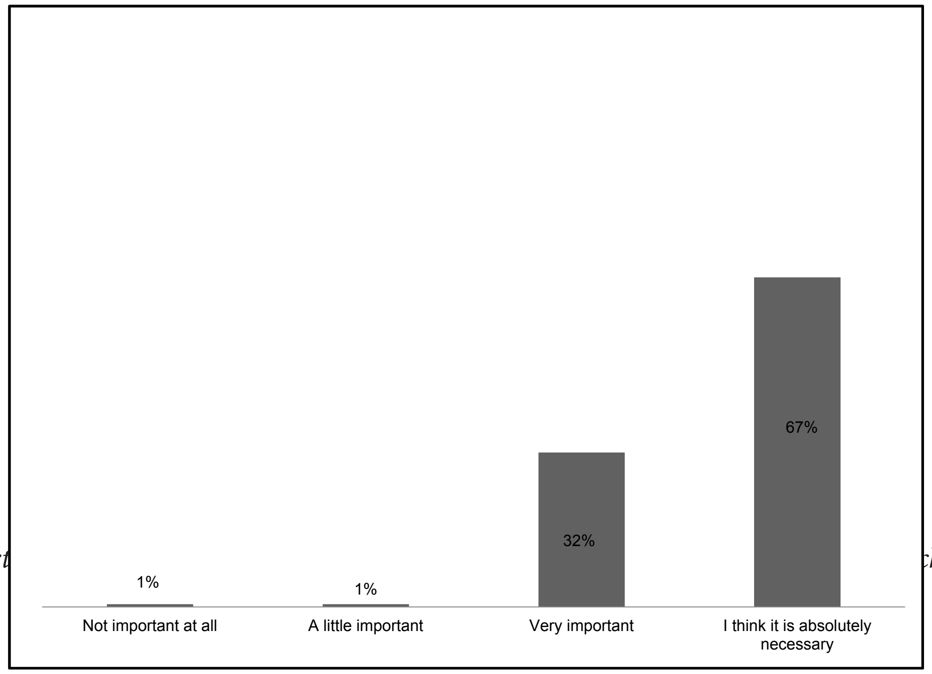

Figure 4. *Part* … *chool with*

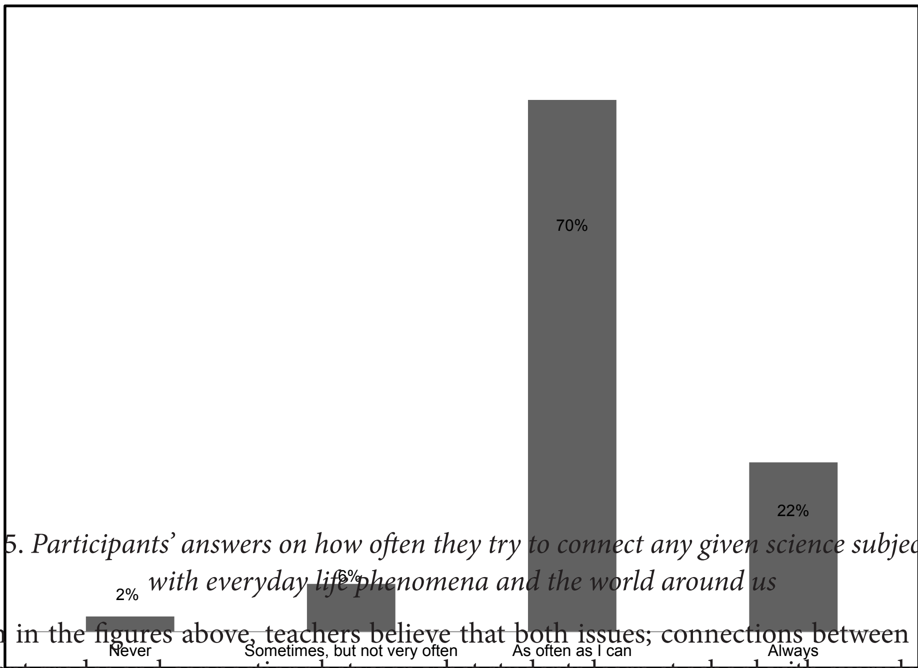

Figure 5. *Participants' answers on how often they try to connect any given science subject taught in class with everyday life phenomena and the world around us*

As seen in the figures above, teachers believe that both issues; connections between science subjects taught in different grades and connections between what students learn at school with everyday life are of high importance. This also explains why they try to make these connections as often as they can. More particularly, teachers believe that the most important out of the two, is building bridges between the school science classroom and everyday life. This finding is in accordance with the idea that one of the most fundamental goals of schooling is to help students apply what they have learned in school to everyday settings of home, community, and workplace (Bransford 2000). Moreover, based on the fact that teachers have also stated that they are not very familiar with the concept of "Big Ideas of Science", we can assume that they try to make these connections either using some other approach or in an uncoordinated way. In none of our workshops, did any participant mention anything about using a similar approach or another set of "Big Ideas of Science" as a reference point.

In the brainstorming part of our workshops, teachers were invited to think about what should be the "Big Ideas of Science" in their opinion. Thus, teachers wrote down concepts and ideas which they believed should be a part of a Big Idea of Science. During the first round of workshops, from this activity, we obtained 747 single answers from participants, regarding concepts and phenomena that according to them, should be included in a Big Idea. These answers where categorized and checked one by one to see if they were covered by our current set. In total, we have found that 32 answers (4%) were not entirely covered by our current set. These answers belonged to three categories; a) quantum mechanics; b) relativity theory; and c) time and scales of the universe. In total, the amount of answers that were not covered by our set was small, which means that no major changes were required. In addition, we gathered 44 "Big Ideas of Science" phrases from the group work of the teachers. These sentences varied a lot in terms of phrasing compared to our own set, but their meanings did not deviate from our own "Big Ideas of Science" set. Finally, after presenting our "Big Ideas of Science" set and asking teachers to comment on it and compare it with the Big Ideas produced by the groups during the workshop, we also gathered 74 additional comments on our set, 54 of which included concrete suggestions. After taking into consideration the suggestions of teachers gathered from the questionnaires and in particular: a) their individual answers on what, in their opinion, are the "Big Ideas of Science" ; b) the "Big Ideas of Science" produced by groups of teachers during the workshops; c) their comments on the current Go-Lab set of "Big Ideas of Science"; and d) the overall discussions during workshops .We made some revisions to our current set of "Big Ideas of Science" and proposed a set of modifications. Aside from minor modifications in the writing of each idea, the main modification we made was to change their presentation a little. As most of our "Big Ideas of Science" can be a bit extensive, therefore, in the spirit of serving the needs of teachers who requested shorter and simpler "Big Ideas of Science", we decided to divide each Big Idea of Science into two parts. The first part is a short sentence which contains very briefly, the essence or the core part of a Big Idea of Science. The second part is the remaining explanatory text of each Big Idea of Science as it is now, which basically compliments the first sentence and completes the meaning of the "Big Ideas of Science". We assume that such a 'hybrid' approach could be more beneficial to students as it can be concise enough to allow them remember the key phrases and at the same time, explanatory enough to allow teachers and students to make easier connections between different phenomena and concepts. The initial and updated Go-Lab "Big Ideas of Science" set are presented below.

Table 2.

The updated set of the Go-Lab set of "Big Ideas of Science"

Initial Go-Lab "Big Ideas of Science" set	*Updated Go-Lab "Big Ideas of Science" set*
1. Energy can neither be created nor destroyed. It can only be transformed from one form to another. The transformation of energy can lead to a change in state or motion.	1. Energy can neither be created nor destroyed. It can only be transformed from one form to another. The transformation of energy can lead to a change in state or motion. Energy can also be converted to mass and vice versa.
2. There are four fundamental interactions/forces in nature; gravitation, electromagnetism, strong-nuclear and weak nuclear forces. All phenomena are due to the presence of one or more of these interactions. Forces act on objects and can act at a distance through respective physical field, causing a change in motion or in the state of matter.	2. There are four fundamental interactions/ forces in nature. Gravitation, electromagnetism, strong-nuclear and weak nuclear forces. All phenomena are due to the presence of one or more of these interactions. Forces act on objects and can act at a distance through respective physical field, causing a change in motion or in the state of matter.
3. The Universe is comprised of billions of galaxies, each of which contains billions of stars and other celestial objects. The earth is a very small part of the Universe.	3. Earth is a very small part of the universe. The Universe is comprised of billions of galaxies, each of which contains billions of stars (suns) and other celestial objects. The earth is a small part of the solar system with the Sun in its centre, which in turn is a very small part of the Universe.
4. All matter in the Universe is made of very small particles. They are in constant motion and the bonds between them are formed by interactions between them.	4. All matter is made of the same very small particles. They are in constant motion and the bonds between them are formed by interactions between them. Elementary particles as we know, form atoms and atoms form molecules. There is a finite number of types of atoms in the universe which are the elements in the periodic table.
5. All matter and radiation exhibit both wave and particle properties.	5. In very small scales, our world is subjected to the laws of quantum mechanics. All matter and radiation exhibit both wave and particle properties. We cannot simultaneously know the position and the momentum of a particle.

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6. Evolution is the basis for both the unity of life and the biodiversity of organisms (living and extinct). Organisms pass on genetic information from one generation to another.	6. Evolution is the basis for both the unity of life and the biodiversity of organisms (living and extinct). Organisms pass on genetic information from one generation to another.
7. Organisms are organized on a cellular basis and require a supply of energy and materials. All life forms on our planet are based on a common key component.	7. Cells are the fundamental unit of life. They require a supply of energy and materials. All life forms on our planet are based on this common key component.
8. Earth is a system of systems which influences and is influenced by life on the planet. The processes occurring within this system shapes the climate and the surface of the planet.	8. Earth is a system of systems which influences and is influenced by life on the planet. The processes occurring within this system influence the evolution of our planet, shapes its climate and surface. The solar system also influences Earth and life on the planet.

In the second round of workshops, as mentioned above, we followed the exact same procedure, the only difference being that in this round, we used the updated version of our Big Ideas set. In this round, we gathered 505 single terms from the brainstorming session. We have found that all single small ideas are covered by the updated Go-Lab set with the exception of the 5 (1%) answers that refer to time and the scales of the universe. However, time and the scales of the universe are two concepts that are connected to every single one of the other concepts and instead of adding another Big Idea, it would make more sense to represent the current set of Big Ideas in the scales of time and space. In this round, another 44 "Big Ideas of Science" phrases where collected from the group work of the teachers. Like in the previous round, although varying in terms of phrasing, teachers' Big Ideas were in accordance with our own set in terms of meaning. About 31 out of 44 phrases (70%) were again brief and laconic. Finally, we also gathered another 73 comments and suggestions from participants, 12 of which were about minor changes. However, all suggestions had a very low number of occurrences (less than 3) and thus, we concluded that no further changes were needed at this point.

During the hands-on part of the workshop teachers had the chance to go through the proposed set of big ideas, discuss it with their peers, reflect on it based on the curriculum they teach and compare it to the big ideas they produced during the brainstorming part. Based on that experience we asked them to what degree they fill that the proposed set of "Big Ideas of Science" is achieving is purpose; offering a set of cross-cutting scientific concepts that describe the world around us and allow us to conceive the connection between different natural phenomena and that could be used as a reference point to connect science concepts in an interdisciplinary way. Below, we present teachers' overall opinion on the Go-Lab "Big Ideas of Science" set, on the use of such a set in the science classroom and on its use as a content organization system. The results in the graph below indicate that the teachers and their trainers that participated in our research are strongly in favor of the Go-Lab set of "Big Ideas of Science". The results of the workshops during the second round also indicate that there is a shift in participants' opinion towards higher rating of the Go-Lab updated set. In round 1, 66% gave a score of 4 out of 5 and 22% gave 5 out of 5 (4.1 average rating).

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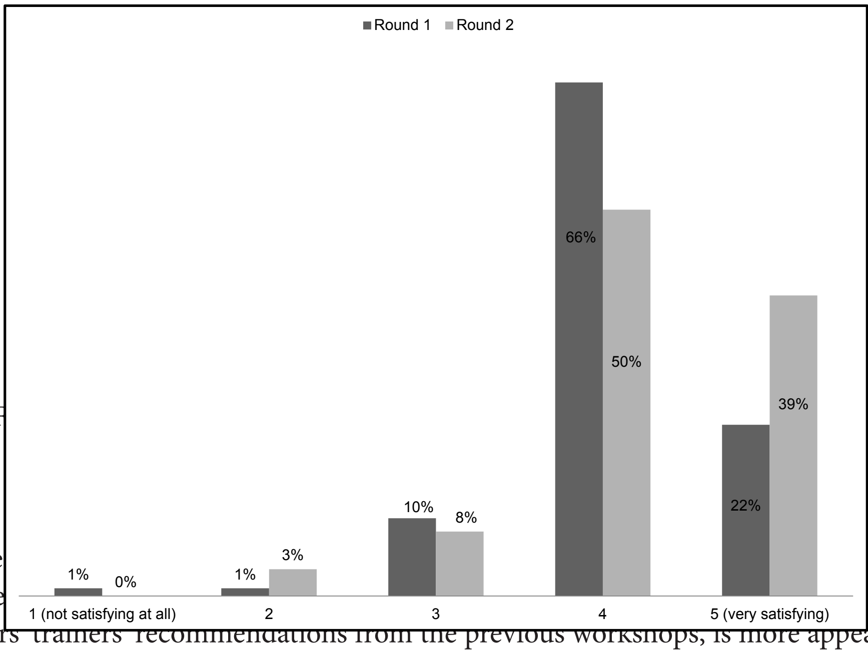

F

In round 2, ... and at the same time the percentage ... ease, 4.2 average score). This shift le ... done based on teachers and teachers' trainers' recommendations from the previous workshops, is more appealing to teachers and suits their needs even better when it comes to using in as an interdisciplinary organization scheme for connecting science concepts.

Figure 7 indicates that 94% of our participants feel that the "Big Ideas of Science" are important or very important when it comes to teaching science. As the "Big Ideas of Science" are meant to be used as a means to connect different science subjects, it is worth comparing Figure 2 to Figure 7. The data presented in these two graphs contain very similar questions. In the pre-questionnaire, in the question "How important do you believe it is to connect the science subjects taught in school with other subjects that students have been taught in the present year or past years?" 51% of the participants have answered "Very important" and 46% of them have answered "I think it is absolutely necessary" (we obtained a total of 97% positive feedback).

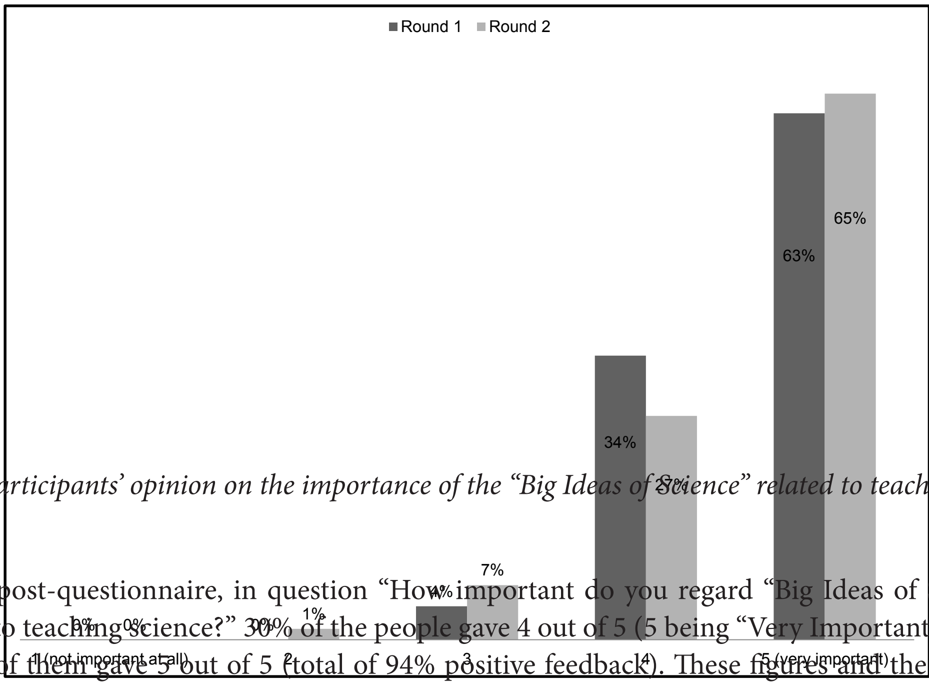

Figure 7. *Participants' opinion on the importance of the "Big Ideas of Science" related to teaching science*

In the post-questionnaire, in question "How important do you regard "Big Ideas of Science" to be, when it comes to teaching science?" 30% of the people gave 4 out of 5 (5 being "Very Important") in the Likert scale and 64% of them gave 5 out of 5 (total of 94% positive feedback). These figures and the swift (18%) of participants' opinion towards a higher rating in the latter question may also indicate that their participation in our workshop has contributed in strengthening their view on the importance of connecting different science subjects in the classroom. In addition, given the high rating the "Big Ideas of Science" have received, we can also conclude that the Go-Lab set of the "Big Ideas of Science" could play the role of a backbone structure in connecting science subjects.

In most educational repositories, the educational content is primarily organized according to science discipline and age group. When selecting a resource some systems recommend additional content based on the science subject or age group, however these recommendations are rarely cross-discipline or interdisciplinary. Teachers cannot find content in such repositories organized using an interdisciplinary scheme allowing them to combine activities coming from different disciplines and that could be used to demonstrate to their students underlying connections between science concepts taught in different science classes. Thus, teachers' opinion during workshops done in round 1, as seen in Figure 7, led us to add an additional question to the post questionnaire used during round 2. Since teachers believe that the "Big Ideas of Science" can be important in teaching science, what we wanted to further investigate was whether a recommendation and organization system of educational content using the "Big Ideas of Science" would be helpful to them when teaching for retrieving and/or combining educational content and activities within an interdisciplinary context of teaching science. The results of this question are presented below in Figure 8.

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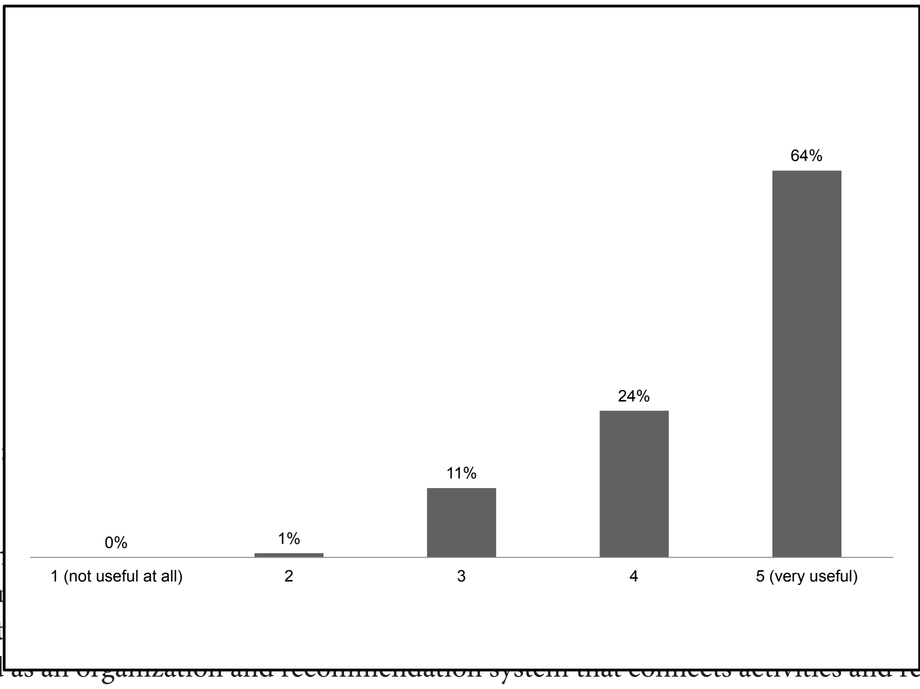

Figure 8. *Pa* ... *ion system*

As it ca ... cipants believe that such a recon ... gly believe that the presence of t ... ial to teachers, especially if used as an organization and recommendation system that connects activities and resources within an interdisciplinary framework.

Conclusion

Building a knowledge structure for students and giving them the opportunity to attach each piece of new knowledge to it consciously and explicitly can contribute a great deal to meaningful learning (Cimer, 2007). When it comes to learning science in particular, such a knowledge structure would work to the benefit of students if it was interdisciplinary, covering all science disciplines. Such an interdisciplinary organization scheme would give the opportunity to students to assess the importance of concepts taught, identify the fundamental ones and understand the connection between science concepts taught in different science classes that may seem irrelevant but in fact have an important underlying connection. Such connections can enable students to understand that all science disciplines are there to help us make sense of our world. By using a set of core big ideas as reference system when teaching science, teachers can enable their students to increase their knowledge retention, look at the bigger picture and understand various aspects of the world around them (Harlen, 2009).

Additionally, this core set of interdisciplinary "Big Ideas of Science" can help teachers swift to a more interdisciplinary teaching style and support collaboration between them. Interdisciplinary learning can help teachers raise students' interest in science – a need teachers are fully aware of (Darby-Hobbs, 2013) – and allow them to build collaborative activities that study the same concept from different viewpoints. This way, the use of the "Big Ideas of Science" as an organization scheme to promote interdisciplinary science learning can contribute in providing a more meaningful context to science curricula and thus improve students' curiosity and a positive thinking towards science (Mandler, Mamlok-Naaman, Blonder, Yayon, and Hofstein 2012).

The study presented in this paper is part of the work done on validating the Go-Lab set of "Big Ideas of Science" through the realization of relative workshops with teachers and teachers' trainers. More specifically we set out to record teachers' and teachers' trainers' understanding of the "Big Ideas of Science" concept, and find out whether such a set of ideas could be helpful for them if used as a tool to connect science concepts; especially concepts taught in different science subject domains and school grades as well as a recommendation system tool for finding activities that are related under an interdisciplinary framework within the Go-Lab repository of online science labs and activities.

The analysis of our data indicates that the majority of teachers, even many with several years of experience in teaching science, are unaware of the term “Big Ideas of Science”. However, the concept is close to their understanding and they can easily relate to it. In addition, the vast majority of teachers and teachers’ trainers in our sample believe that connecting science subjects taught in school to each other and to the world around them is very important for students and thus, they try to make these connections in their class as often as possible. This tendency is in accordance with students’ views who also prefer a science education closer to everyday life (Aikenhead, 2006).

Based on the input and comments gathered from the teachers who participated in the first round of validation, we made small modifications to our original set of Big Ideas. The results from the second round of validation during which we used our updated “Big Ideas of Science” set and more specifically based on the question about evaluating our set, showed that the updated set of Big Ideas had a higher score indicating that the updated version was closer to teachers understanding and perception of the concept compared to the original version. Evidence also show that the updated version of the Go-Lab set had a greater impact on workshop participants, as they gave it a higher score compared to the results of the first round when asked to evaluate our Big Ideas of Science set. In total, 82% of the teachers who participated in our workshops gave the Go-Lab “Big Ideas of Science” set, a score of 4 or 5 out of 5, while 94% of them believe that the concept of the “Big Ideas of Science” is quite an important notion and could be a useful tool when it comes to connecting science concepts in class for students, especially when concepts come from different science disciplines. This could mean that the “Big Ideas of Science” could give teachers the capacity to create interdisciplinary learning experiences that allow students to integrate knowledge, skills, and methods of inquiry from several subject areas, which is a pivotal skill towards successful teaching (Council, T. A., & National Research Council, 2001).

Overall, teachers’ answers and comments during discussions indicate that they are not provided with the means that will allow them to collaborate effectively and be in a position to work on making connections, between science subjects. According to them, a set of “Big Ideas of Science” like the one presented in the framework of the Go-Lab project could play the role of such a backbone structure that the teachers can use in their class to communicate the matters under discussion in a more constructive way, thus, allowing students to build on existing knowledge and experience.

In addition, when used in the framework of interdisciplinary activities, the “Big Ideas of Science” set could facilitate students in making stronger and deeper connections between facts, concepts and phenomena coming from the same or different science disciplines. They can help learners possess relevant concepts and propositions that can serve to anchor the new learning and assimilate new ideas, which is one of the requirements of meaningful learning (Novak, 1993). However, the introduction of such an approach would require properly designed materials for students and a training framework for teachers. If used as a reference guide for connecting science concepts, the “Big Ideas of Science” could also be used as a way to organize science interdisciplinary activities and help teachers from different disciplines collaborate using one or more big ideas as common ground. An organization of science content using the “Big Ideas of Science” goes beyond curricula thus making it unaffected by the constant changes that occur in the science curricula of many countries. In an era when teachers search online for inspiration for their activities, they communicate with teachers from other countries and share ideas and activities with them, such a “curriculum-proof” organization of content and activities could have significant potential.

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RESEARCH REPORT

Comparing Robert Noyce Scholars and Non-Robert Noyce Scholars Perceptions of Teaching

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Abstract: *Staffing high schools with highly qualified math and science teachers continues to be a challenge for school districts across the U.S. (NCTAF, 2010; Ingersoll & Merril, 2010). One way to address this challenge is to offer financial incentives, in the form of scholarships or grants, for high performing college students to become high school mathematics or science teachers. Oftentimes, attached to these financial incentives are service commitments to which recipients must agree to teach for a specified number of years in a high-need school or district. Investigating the impact these types of scholarship programs have on the high school math and science teacher staffing issue is an area that warrants more research. To help identify some characteristics of students involved in these types of financial incentive programs, our study investigates how the Robert Noyce Scholarship Program influenced students' decisions to become a high school mathematics or science teachers and their dispositions about teaching in schools. In this study, we administered a 70 item survey to 61 participants (29 experimental group, 32 control group) during the summer of 2015. Latent variables were created using Exploratory Factor Analysis and differences between the experimental and control groups were tested with the Mann-Whitney U and Chi-Square tests. Findings indicate statistically significant differences in three areas: (a) scholarship recipients' decisions to become a high school mathematics or science teacher, (b) plans for graduate education, and (c) teacher preparation.*

Keywords: STEM teacher preparation, Robert Noyce Teaching Scholarship, teaching in high-need schools

Comparing Robert Noyce Scholars and Non-Robert Noyce Scholars Perceptions of Teaching

The flow of new teachers into classrooms around regions of the U.S. is decreasing and is effecting the stability and sustainability of the teacher workforce. During the 20th century, the supply of teachers generally met the demand. New teachers viewed their job as a lifelong career from which they would retire, and experienced teachers made up the majority of teachers in the profession (Carroll, 2007; Ingersoll & Merril, 2010). At the end of the 20th century and beginning of the 21st century, however, the number of experienced teachers in schools decreased (National Commission on Teaching and America's Future [NCTAF], 2010) and new teachers started leaving the profession at detrimentally high rates. Though the estimates for beginning teacher attrition rates vary, it is evident that these rates are high and negatively impact both the teacher supply and teaching quality. Some researchers report that 30% of new teachers leave the profession within their first five years of teaching (Ingersoll & Merril, 2010; NCTAF, 2010) while others suggest higher rates between 40% and 50% (Grissmer & Kirby, 1987, 1992, 1997; Ingersoll, 2003). Though not all estimates are equal, the fact that about one in three new teachers leave the profession is evidence that the stability and sustainability of the

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teacher workforce is at risk.

The severity of the teacher shortage problem varies among grade levels, disciplines, and geographic areas. A teacher shortage area is a grade and discipline specific to a geographic area in which the U.S. Secretary of Education determines there is an inadequate supply of teachers (U.S. Department of Education, 2014). Bilingual education, foreign language, mathematics, science, and special education are some of the examples of teacher shortage areas. The continual lack of effective teachers in these teacher shortage areas has negatively impacted the quality of instruction and has created a cycle of ineffective teaching in classrooms that has numerous adverse implications (Darling-Hammond, 2007). This problem is even more acute in schools that serve low-income students or schools that serve predominantly Black or Hispanic students where there are high percentages of non-certified teachers (Carroll, 2007; United States Department of Education, 2015). Focusing on recruiting and retaining high quality, effective teachers in low-income schools and in teacher shortage areas has gained momentum in the national spotlight and is now at the forefront of many political initiatives.

The Robert Noyce Teacher Scholarship Program (TSP), funded by the National Science Foundation (NSF), is one example of a government initiative that was enacted to address the critical need of teachers in high-need schools or districts, specifically in the content areas of science, technology, engineering, and mathematics (STEM). This scholarship program encourages talented STEM students to pursue teaching careers in mathematics and science by providing institutions of higher education (IHE) funding to recruit "individuals with strong STEM backgrounds who might otherwise not have considered a career in K-12 teaching" (NSF, 2012, p. 7). Begun by an Act of Congress in 2002, the Robert Noyce TSP was reauthorized under the America COMPETES Act in 2007 and the American COMPETES Reauthorization Act of 2010. The program was designed to increase the number of STEM teachers with strong STEM content knowledge to teach in high-need school districts. STEM students who are awarded the scholarship receive substantial funds – sometimes as much as $20,000 – and as part of their scholarship they are required to complete one year of teaching in a high-need public school district for each semester of financial support. The Robert Noyce TSP has awarded scholarships to a sizable number of high achieving STEM students throughout the United States, but the actual impact the program has had on recruiting and retaining high-quality teachers in high-need schools is unclear.

Uncovering the role that scholarships play in influencing students to enter the teaching profession in high-need schools is a complex task. Many factors, both intrinsic and extrinsic, contribute to the decisions students make to enter the teaching profession. Some scholarship recipients cite reasons like wanting to change society and children, teaching subject matter they are passionate about, and being a positive role model for children (Bull, Marks, & Salyer, 1994; Henry, Bastian, & Smith, 2012) as reasons for entering the teaching profession. Other scholars may have a tainted portrayal of low-income urban areas and, as such, have more of a missionary perspective that drives them to enter the teaching profession and "save" the underprivileged students (Irizarry, 2009). This general desire to help others is a common characteristic found in effective teachers (Stronge, 2007). Internal factors, such as the ones mentioned above, contribute to the scholarship recipients' decisions to enter teaching, but there are also external reasons such as teaching scholarships.

Scholarships that are designed to combat the teacher shortage problem and increase the number of teachers in high-need fields generally include some financial incentive. The extent to which the financial incentive effects the scholar's decision to become a teacher, or teach in low-income schools, is difficult to measure. However, one factor that was found to impact scholars' decisions to accept the funding was the amount awarded. Scholars' were influenced more when the financial incentive covered a higher proportion of their tuition (Darling-Hammond, 2007; Henry et al., 2012; Liou & Lawrenz, 2011). For the Noyce Teaching Scholarship specifically, some research has shown that the financial incentive did not influence the scholars' decisions to enter the teaching profession; many of the Noyce Scholars would have entered the teaching profession regardless of the financial incentive (Bull et al., 1994; Liou, Desjardins, & Lawrenz, 2010). Liou & Lawrenz

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2011) found, however, that Noyce Scholars who originally did not consider a career in teaching, the financial incentive did have a larger impact on their decision to enter the teaching profession. Competitive scholarships appear to attract individuals with significantly higher academic credentials and higher levels of human capital into teaching, but unless the scholarship programs require recipients to work in high-need schools, they tend to teach in schools and classrooms with more high-achieving and low-poverty students (Henry et al., 2012). The financial incentive offered by the Noyce Scholarship had the most influence on recruiting teachers to high-need schools and completing their certification program, but less of an influence on staying in a high-needs schools for long periods of time (Liou, Desjardins, & Lawrenz, 2010; Liou, Kirchhoff, & Lawrenz, 2010; Liou & Lawrenz, 2011). Using scholarships as mechanisms to recruit teachers into high need fields has its own set of challenges. Thus, it is necessary to continue to study these challenges and modify them to meet the needs of the forecasted teacher market.

Though some research exists on factors that influence Noyce Scholars' decision to enter the teaching profession and how the financial incentive of the scholarship impacted their decision to teach, little research has been conducted on characteristics unique to Noyce Scholars. Comparing the perceptions of Noyce Scholars on various aspects of teaching and the teaching profession with a similar group of teachers that did not receive the Noyce scholarship can possibly shed some light on differences between Noyce Scholars and non-Noyce Scholars. The research questions guiding this study are:

1. How do the Noyce Scholars perceptions of teaching and of the teaching profession differ from the perceptions of a group of non-Noyce Scholars who were certified through the same teacher preparation program?

2. How do Noyce Scholars decisions about becoming a teacher, about staying in the teaching profession, and about plans for graduate education differ from a group of non-Noyce Scholars who were certified through the same teacher preparation program?

Methodology

Design

For this study, we used a quasi-experimental design and applied stratified matched sampling to compare the characteristics and perceptions of participants who received a Noyce scholarship to those participants who did not. Targeted participants were students who received their secondary mathematics or science teaching certification from a university in the southwestern region of the United States and who all participated in the same secondary undergraduate teacher preparation program. The data for this study were generated from one survey that was administered electronically to 61 participants during the summer of 2015.

Participants

The pool of participants for this study was comprised of teachers who were all certified from the same teacher preparation program during 2002-2014. The teacher preparation program from which the participants graduated was a secondary, undergraduate program at a large, research university located in the South Central region of Texas. The program certifies students who are working toward a bachelor's degree in mathematics or science to be teachers in Texas secondary schools. Each student in the program takes at least 18 hours of education courses, observes in secondary schools for at least 120 hours, and completes either a 12-week student teaching experience or a one-year internship. All participants in this study received their initial teaching certification for either grades 7 or 8 to 12.

From 2002-2007, and again from 2009-2014, the preparation program received two Robert Noyce Teaching Scholarship Grants providing funds to award high achieving students a scholarship to help fund their

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education. Each student was a mathematics or science major with at least a 3.0 average. At the beginning of each academic semester, a selection committee was appointed to review the applications and select a set of Noyce Scholars. Throughout the 10 years of funding, 71 students were selected as Noyce Scholars.

The Noyce Scholars received $5,000 each semester for one to four semesters while agreeing to teach in a high-need school district for one year per each semester funded. If the agreement was not fulfilled, students had to pay back the money awarded in scholarship funds as an interest-bearing loan.

At the time of this study, 61 of the 71 Noyce Scholars were employed in the education profession and eligible to participate in the study. Of the 10 ineligible, one was in graduate school, six no longer had valid teaching certificates, one was teaching out of the state, and no contact information was found for the remaining two. Email messages were sent to all 61 eligible scholars inviting them to participate with a stipend of $675. Fifteen did not respond (of those 6 had no functional email address), 19 declined to participate in the study, and 29 agreed to participate in the study.

The selected control group (referred to as non-Noyce Scholars) was comprised of teachers who were certified through the same teacher preparation program during 2002-2014, but did not receive a Noyce Scholarship. An email message was sent describing the terms of the study with a stipend of $675. Three rounds of email messages were sent to the 178 eligible teachers for the control group and 130 did not respond (of those 9 had no functional email address), 9 declined to participate in the study, and 39 agreed to participate in the study (22% response rate).

The 39 non-Noyce Scholars who agreed to participate in the study were stratified on two items–school locale code and years of experience in the education profession–and matched to the 29 selected Noyce Scholars. The school locale code (National Center for Educational Statistics [NCES], 2006) classifies schools based on its proximity to an urbanized area. The number of years of experience were examined and matched, as close as possible, to the school locale code and number of years of experience of the Noyce Scholars. This process resulted in the omission of seven non-Noyce Scholars and created a sample size of 29 (Noyce Scholars) and 32 (non-Noyce Scholars). This was intentional to account for any attrition that could occur throughout the three years of the larger, longitudinal study. Summaries of the demographics and employment characteristics of the participants are shown in Table 1.

Table 1.

Demographics and Employment Characteristics of Study Participants

Characteristic	Noyce	Non-Noyce	Total
Gender			
Female	19	26	45
Male	10	6	16
Ethnicity			
White, Non-Hispanic	26	28	54
Black, Non-Hispanic	1	0	1
Hispanic	1	2	3
Asian or Pacific Islander	1	1	2
Other	0	1	1
School Locale			
City: Large/Midsize/Small	4/2/2	6/2/4	10/4/6
Rural: Fringe/Distant	6/0	3/3	9/4
Suburb: Large	10	8	18
Town: Distant/Fringe/Remote	0/0/3	2/2/0	2/2/3

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2014-2015 Job Title			
School Administrator	5	1	6
District Level Administrator	0	1	1
Classroom Teacher	20	27	47
Other	4	3	7
Number of Years of Experience			
0	2	1	3
1-3	10	14	24
4-5	8	10	18
> 5	11	8	19

Instrumentation

The Summer 2015 survey was adapted from two other surveys; the Schools and Staffing Survey (SASS) created by the National Center for Educational Statistics (NCES, 2012) and the Noyce Scholar Survey developed at the University of Minnesota for the Noyce Evaluation Report (University of Minnesota, 2012). Questions were selected from these two surveys because both survey instruments had been previously administered and were found to be reliable and valid (NCES, 2012; Liou & Lawrenz, 2009). Additionally, using questions adapted from these surveys allows for comparison of the results from this study to other studies.

The Summer 2015 survey contained 70 items that were classified in into nine sections: Personal Information (PI), Employment Information (EI), Decisions on Becoming a STEM Teacher (DBST), Mentoring and Induction Experiences (MIE), Impressions of Teaching and Current Job (ITCJ), Plans for Graduate Education (PGE), Teacher Preparation (TP), School Climate and Teacher Attitudes (SCTA), and the Noyce Scholarship (NS).

The questions on the survey had a variety of answer types: categorical scales, ordinal scales, and open-ended. Most of the ordinal scale questions had multi-part statements where participants ranked the statements on four- or five- point Likert scales.

Procedures

Each participant completed the survey. Questions from the categories of PI, EI, MIE, and NS were not used because the categories did not align with the research questions guiding this study. Additionally, because of the similarity of the questions in the categories ITSC and SCTA, ITSC questions were merged into SCTA creating four categories to be analyzed: DBST, PGE, TP, and SCTA

Each category contained either ordinal or nominal scales. DBST and PGE each contained two nominal scale questions; TP contained two ordinal scale and one nominal scale question; and SCTA contained 10 ordinal scale and three nominal scale questions, giving a total of eight nominal scale and 12 ordinal scale questions. These ordinal scales each had multiple statements that participants rated on 4- or 5-point Likert-type scales ranging from "Strongly Agree" to "Strongly Disagree".

For the eight questions with nominal scales, either the Mann-Whitney U or the Chi-Square test was used to determine any significant differences between participants who received a Noyce scholarship and those who did not. For the 12 ordinal scale questions, an Exploratory Factor Analysis (EFA) was conducted to determine the factor structure of the statements within each question. For seven of the 12 ordinal scale questions, the individual EFAs identified that all statements within the question loaded on a single factor that accounted for between 44 to 70% of the variance for each factor. The Cronbach's Alpha for each of the factors was greater than 0.70 ($\alpha > 0.70$). For each of these seven latent variables, the following scales were named: Performance of School Leadership, Problems in Schools, Perceptions of Actual Control in the Classroom, Teacher Influence Over School Policy, Perceptions of Preparedness for 1st Year of Teaching, Opportunities

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within Teacher Certification Program, and Perceptions of Formal Evaluations. Table 2 shows the Cronbach's alpha, the eigenvalue, and the percent variance explained by each of the seven latent variables.

For the remaining five questions that did not load on a single factor with α > 0.70, further analysis was required. Four had α < 0.70 and the fifth question loaded on multiple factors, but did not have meaningful groupings. Thus, a reliability analysis was conducted to determine if the alpha value would increase if some statements within each question were omitted. For two, it was determined that the alpha value would increase and exceed 0.70 if some of the statements were omitted. Thus this statement was omitted to increase α to 0.726 and for the other question, two statements were omitted to increase α to 0.748. Two latent variables were created for these two questions; Perceptions of State Assessments and Job Satisfaction and Enthusiasm. Table 2 shows the Cronbach's alpha, eigenvalue, and the percent variance explained by each of these two latent variables.

Table 2.

Cronbach's Alpha, Eigenvalues, and Percent Variance for Seven Latent Variables.

Latent Variable	Category	Cronbach's Alpha	Eigenvalue	% variance explained
Performance of School Leadership	SCTA	0.91	4.913	61.414
Problems in Schools	SCTA	0.905	5.472	54.718
Perceptions of Actual Control in the Classroom	SCTA	0.776	2.986	49.768
Teacher Influence Over School Policy	SCTA	0.778	3.112	44.462
Perceptions of Preparedness for 1st Year of Teaching	TP	0.878	4.409	55.118
Opportunities within Teacher Certification Program	TP	0.823	2.673	66.814
Perceptions of Formal Evaluations	SCTA	0.768	2.09	69.665
Perceptions of State Assessments*	SCTA	0.726	2.17	45.783
Job Satisfaction and Enthusiasm**	SCTA	0.748	2.56	51.296

* one statement removed ** two statements removed

For the third of the four questions that underwent the additional reliability analysis, the alpha value still did not exceed 0.70 when the statements were omitted. For this question, an alpha value of 0.662 was deemed acceptable and a scale titled School Environment was created. The School Environment scale had an eigenvalue of 1.999 and this variable explained 49.974% of the variance. The alpha value for the fourth question that underwent additional reliability analysis would not increase to an acceptable alpha level (α = 0.383), hence this question was analyzed on a statement-by-statement basis with a Mann-Whitney U test.

For the one ordinal scale question that loaded on multiple factors but did not have meaningful groupings, further reliability analysis was conducted, but it continued to fail to have meaningful groupings where all alpha values exceeded 0.70. The first EFA on this question revealed five factors, but none of the statements within the factors could be labeled with a meaningful title and α > 0.70 for some of the factors by α < 0.70 for other factors. Thus, additional EFAs were conducted that forced the statements to load on four, three, two, and one factor. For all of these four EFAs, reliability and creating meaningful groupings continued to be a problem resulting in this

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question being analyzed on a statement-by-statement basis with a Mann-Whitney U test.

After all EFAs and additional analyses were conducted, it was determined that of the 12 ordinal scale questions, 10 loaded on individual factors and two did not load sufficiently on any factors. As such, ten latent variables were created and statement-by-statement analyses were conducted on the two questions that failed the EFA. The 10 latent variables and the two questions analyzed on a statement-by-statement basis did not meet the normal distribution assumption and equal variance requirement for parametric tests, so Mann-Whitney U tests were conducted throughout the study to determine any significant differences between participants who received a Noyce scholarship and those who did not. For the latent variables, factor scores were calculated and used in the Mann-Whitney U tests.

Results

The responses from the survey were analyzed to help determine any statistically significant differences between two independent groups of participants across four categories of the survey. The four categories were: Decisions on Becoming a STEM Teacher (DBST), Plans for Graduate Education (PGE), Teacher Preparation (TP), and School Climate and Teacher Attitudes (SCTA). Some questions within categories were analyzed on a statement-by-statement basis and others had latent variables created via an Exploratory Factor Analysis. For the latent variables, corresponding factor scores were calculated and Mann-Whitney U tests were used to determine any significant differences between the groups on both the latent variables and the statement-by-statement analysis.

Decisions on Becoming a STEM Teacher (DBST)

The DBST category contained two nominal scale questions. The first question was "Did any of the following help you decide to become a STEM teacher?". A list of nine statements followed this question and participants responded to each statement with "yes" or "no". A Mann-Whitney U test produced statistically significant difference between the groups on two of the nine statements. For the first significant statement, "I like the flexibility and/or autonomy of STEM teaching.", results of the Mann-Whitney U test ($p = 0.011$) indicated that non-Noyce participants were influenced more by the flexibility and/or autonomy of STEM teaching ($M = 0.88$, $SD = 0.336$) than the Noyce participants ($M = 0.59$, $SD = 0.501$). Glass' effect size value ($\Delta = 0.863$) suggested a high practical significance.

The second significant difference found in the first question concerned the statement "I feel that a teaching career is/will be conducive to my family life". Results of the Mann-Whitney U test ($p = 0.005$) indicated that non-Noyce participants were influenced more by a teaching career being conducive to family life ($M = 0.88$, $SD = 0.336$) than Noyce participants ($M = 0.55$, $SD = 0.506$). Glass' effect size value ($\Delta = 0.982$) suggested a high practical significance. Table 3 shows the descriptive statistics and results of the Mann-Whitney U test on all nine statements.

The second question in the DBST category that produced a statistically significant difference ($p = 0.033$) between non-Noyce ($M = 1.69$, $SD = 0.471$) and Noyce participants ($M = 1.41$, $SD = 0.501$) was "At what point in your life did you decide to become a STEM teacher?". For this question, participants chose one of the following three responses: Childhood/adolescence (age 18 or before), Early adulthood (age 19-22), or Adulthood (age 23 or older).

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Table 3.

Descriptive Statistics and Mann-Whitney U Test Results for the Question "Did any of the following help you decide to become a STEM teacher?".

Question	Noyce		Non-Noyce		Mean	
	Mean	*SD*	Mean	*SD*	Diff	M-W U
I like sharing my subject with others.	0.93	0.258	0.94	0.246	-0.01	*p* =.92
I like working with young people.	1.03	0.186	1.03	0.177	0	*p* =.944
I like having summers off.	0.76	0.435	0.75	0.44	0.01	*p* =.938
I like the flexibility and/or autonomy of STEM teaching.	0.59	0.501	0.87	0.336	-0.28	*p* =.011*
I feel that a teaching career is/will be conducive to my family life.	0.55	0.506	0.87	0.336	-0.32	*p* =.005*
I feel that I have a talent for teaching STEM.	0.9	0.31	0.87	0.336	0.03	*p* =.794
I feel this career allows me to 'make a difference' in the world.	0.97	0.186	0.97	0.177	0	*p* =.944
I have family members that are/were teachers.	0.55	0.506	0.62	0.492	-0.07	*p* =.564
Other people encouraged me to become a STEM teacher.	0.38	0.494	0.47	0.507	-0.09	*p* =.484

For the analysis, Childhood/adolescence was coded as "1", Early adulthood as "2", and Adulthood and "3". The frequency counts indicate that significantly more Noyce participants decided to become a STEM teacher at the age of 18 (n = 17) than non-Noyce (n = 12). Additionally, significantly more non-Noyce participants decided to become a STEM teacher between the ages of 19 and 22 (n = 22) than Noyce (n =10). Glass' effect size value (Δ = 0.594) suggests a moderate practical significance.

Plans for Graduate Education (PGE)

The PGE category contained two dichotomous (yes or no), nominal scale questions. For the first, "Since graduating from the university have you taken any graduate level classes?", a chi-square test indicated a statistically significant difference $\chi^2(1)=4.601$, $p < 0.05$ between groups indicating that significantly more Noyce participants (55%) took some graduate level classes since graduating from the university than non-Noyce (28%). For the second question, "Since graduating from the university have you received any advanced degrees?", a chi-square test indicated a statistically significant difference $\chi^2(1)= 4.824$, $p < 0.05$ between groups indicating that significantly more Noyce participants (45%) received advanced degrees since graduating from the university than non-Noyce (19%).

Teacher Preparation (TP)

The TP category contained one nominal scale question that contained multiple dichotomous statements and two latent variables (formed in the EFA). The dichotomous statements were analyzed for differences between groups on a statement-by-statement basis. The two latent variables in TP were: (a) Opportunities within Teacher Certification Program and (b) Preparedness for 1st Year of Teaching.

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The nominal scale question, "Which of these were part of your experience in your teacher certification program?", was analyzed on a statement-by-statement basis with participants responding with "yes" or "no" to a list of 14 statements. A Mann-Whitney U test indicated a statistically significant difference between the groups on only one statement - "Opportunities to interact with children from different cultures" ($p = 0.043$) indicating that Noyce participants had significantly more opportunity to interact with children from different cultures ($M = 1.34$, $SD = 0.484$) than the non-Noyce participants ($M = 1.12$, $SD = 0.336$). Glass' effect size value ($\Delta = 0.655$) suggested a moderately high practical significance. The descriptive statistics and results of the Mann-Whitney U test for each statement within this question are provided in Appendix A.

The two latent variables for the TP category were Opportunities within Teacher Certification Program ($M = 0.004$, $SD = 0.922$) and Preparedness for 1st Year of Teaching ($M = -0.176$, $SD = 1.01$). A Mann-Whitney U test found no statistically significant differences between the two groups. The Opportunities within Teacher Certification latent variable had four statements that participants rated on a 5-point scale. The statements related to the question "In your teacher certification program, how much opportunity did you have to do the following" with 5 representing "Extensive Opportunity" and 1 represented "none". The means from each group ranged from 2.28 to 3.13. The Preparedness for 1st Year of Teaching had eight statements that participants rated on a 4-point scale. The statements referred to the prompt "In your first year of teaching, how well prepared were you to…" and the ratings ranged from 1 (not at all prepared) to 4 (very well prepared). The means from each group ranged from 2.14 to 3 with the exception of the statement "Teach your subject matter". For this statement, Noyce Scholars had a slightly lower means ($M = 3.31$) than the non-Noyce Scholars ($M = 3.53$).

School Climate and Teacher Attitudes (SCTA)

The SCTA category contained 13 questions (3 were categorical and 10 were ordinal). The three categorical questions were analyzed on a statement-by-statement basis for differences between groups. The results of the EFA indicated that two of the 10 ordinal questions needed to be analyzed as individual questions for differences between groups. Thus, this category contained five statement-by-statement analyses. Latent variables were created for the remaining eight ordinal questions and their corresponding factor scores were analyzed for differences among groups.

The first of the three categorical questions were "How long do you plan to remain in your current position?". Participants chose from eight statements (as long as I am able, until I am eligible for retirement benefits from this job, until I am eligible for Social Security benefits, until a specific life event occurs (e.g., parenthood, marriage), until a more desirable job opportunity comes along, definitely plan to leave as soon as I can, undecided at this time, other) and results of a Mann-Whitney U test indicated no statistically significant difference among groups. Table 4 shows the percentage of Noyce and non-Noyce scholars that selected each statement. Those participants that selected "other" reported the following statements when asked to specify: one more year, as long as it is a good position for my family, for several years before moving into administration, until I reach retirement age and then I would like to work in academia teaching others how to teach, until I become a professor, and I am working on acquiring a principal position in the coming years.

Table 4.

Percentage of Each Group's Responses to Question "How long do you plan to remain in your current position?".

Statement	Noyce	Non-Noyce
As long as I am able.	41%	56%
Until I am eligible for retirement benefits from this job.	0	0
Until I am eligible for retirement benefits from a previous job.	0	0
Until I am eligible for Social Security benefits.	0	0
Until a specific life event occurs (e.g., parenthood, marriage).	4%	9%
Until a more desirable job opportunity comes along.	21%	3%

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Definitely plan to leave as soon as I can.	0	0
Undecided at this time.	24%	22%
Other	10%	10%

The second categorical question was "If you could go back to your college days and start over again, would you choose to teach again or not?". Participants ranked their responses on a 5-point scale. The percentages of responses to this question are show in Table 5. Results of the Mann-Whitney U test indicated no statistically significant difference among groups for any of these responses.

Table 5.

Percentage of Responses to Question "If you could go back to your college days and start over again, would you choose to teach again or not?".

	Certainly would (5)	Probably would (4)	Chances are about even (3)	Probably would not (2)	Certainly would not (1)	Mean	*SD*
Noyce	73%	17%	10%	0	0	4.62	0.677
non-Noyce	60%	25%	12%	3%	0	4.41	0.837

The third categorical question was "Which of the following describes your employment during the 2014-2015 school year?". Percentages and descriptive statistics for this question are show in Table 6. Results of the Mann-Whitney U test ($p = 0.016$) indicated that significantly more Noyce participants were employed in a high-needs schools ($M = 1.28$, $SD = 0.591$) than the non-Noyce participants ($M = 1.46$, $SD = 0.647$). The participants that chose the response "other" reported that they were not sure of their school's high-need status.

Table 6.

Percentages and Descriptive Statistics for the Question "Which of the following describes your employment during the 2014-2015 school year?".

	I worked in high needs (3)	I worked in another type of school (2)	Other (1)	Mean	*SD*
Noyce	79%	14%	7%	1.28	0.591
non-Noyce	47%	44%	9%	1.46	0.647

In the SCTA category there were two ordinal questions that did not reliably load on a factor. The first question was "How much do you agree or disagree with each of the following statements about teaching?". Participants ranked the five statements relating to satisfaction with their current job on a 5-point scale from "Strongly Agree" to "Strongly Disagree". A Mann-Whitney U test was conducted on a statement-by-statement basis but no statistically significant results were found. Table 7 shows the descriptive statistics and results of the Mann-Whitney U test.

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Table 7.

Descriptive Statistics and Results of Mann-Whitney U test for Question "How much do you agree or disagree with each of the following statements about teaching?".

Statements	Noyce		non-Noyce		Diff. of	M-W-U
	Mean	*SD*	Mean	*SD*	Means	
I am satisfied with my current job.	4.41	0.628	4.22	0.941	4.31	p =.455
I really dislike STEM teaching.	1.1	0.557	1.41	0.712	1.26	p =.090
If I had to do it all over again, I would choose the same teacher preparation program and/or route into teaching.	4.34	0.814	4.44	0.759	4.39	p =.657
If I had to do it all over again, in view of my present knowledge, I would become a teacher.	4.34	0.721	4.34	0.701	4.34	p =.961
I am likely to assume a leadership position (e.g., lead teacher, depart. chair, official or unofficial mentor)	3.48	1.805	3.66	1.335	3.57	p =.816

The second question that did not reliably load on a factor was "To what extent do you agree or disagree with each of the following statements?". Participants ranked 18 statements relating to various aspects of school climate and teacher attitudes on a 4-point scale from "Strongly Agree" to "Strongly Disagree". A Mann-Whitney U test was conducted on a statement-by-statement basis but no statistically significant results were found. The descriptive statistics and results of the Mann-Whitney U test for this question are shown in Appendix B.

Finally, a Mann-Whitney U test was conducted on the eight latent variables associated with this category. The eight latent variables were: Performance of School Leadership, Problems in Schools, Perceptions of Actual Control in the Classroom, Teacher Influence Over School Policy, Perceptions of Formal Evaluations, School Environment, Perceptions of State Assessments, and Job Satisfaction and Enthusiasm. A Mann-Whitney U test indicated no statistically significant differences between the groups on any of the eight latent variables. The Performance of School Leadership latent variable had eight statements that participants rated on a 5-point scale. The statements related to the question "How effectively do you feel the principal or school head performed each of the following at last year's school" and the ratings ranged from 1 (not at all effectively) to 5 (extremely effectively). The means of both groups ranged from 2.97 to 3.69.

The Problems in Schools latent variable had ten statements that participants rated on a 4-point scale. The statements related to the question "To what extent is each of the following a problem in this school?" with ratings from 1 (not a problem) to 4 (serious problem). The means of both groups ranged from 1.75 to 2.83.

The Perceptions of Actual Control in the Classroom latent variable had six statements that participants rated on a 4-point scale. The statements related to the question "How much actual control do you have in your classroom at your last school over the following areas of your planning and teaching?". Ratings ranged from 1(no control) to 4 (a great deal of control). The means of both groups ranged from 2.5 to 3.77.

The Teacher Influence Over School Policy latent variable had seven statements that participants rated on a 4-point scale. The statements related to the question "How much actual influence do you think teachers have over school policy at your last school in each of the following areas?". Ratings ranged from 1(no influence) to 4 (a great deal of influence). The means of both groups ranged from 1.66 to 2.48 with higher means of 2.59 (Noyce) and 3.22 (non-Noyce) for the one statement regarding establishing curriculum.

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The Perceptions of Formal Evaluations latent variable had three statements that participants rated on a 4-point scale. The statements related to the question "To what extent do you agree or disagree with each of the following statements about the formal evaluation of your work as a teacher last school year?". Ratings ranged from 1 (strongly disagree) to 4 (strongly agree). The means of both groups ranged from 2.94 to 3.67.

The School Environment latent variable had four statements that participants rated on a 5-point scale. The statements related to the question "Please rate your school environment as high, medium, or low on the features listed below.". Ratings ranged from 1 (very low) to 5 (very high). The means of both groups ranged from 3.28 to 3.9.

The Perceptions of State Assessments latent variable had five statements that participants rated on a 4-point scale. The statements related to the question "To what extent do you agree or disagree with each of the following statements about the state assessment program during the 2014-2015 school year?". Ratings ranged from 1 (strongly disagree) to 4 (strongly agree). The means of both groups ranged from 2.74 to 3.32 with the exception of one statement. The statement "I did not receive adequate support in preparing my students for the assessments." had means of 1.79 (Noyce) and 1.73 (non-Noyce).

The Job Satisfaction and Enthusiasm latent variable had seven statements that participants rated on a 4-point scale. The statements related to the question "To what extent do you agree or disagree with each of the following statements?". Ratings ranged from 1 (strongly disagree) to 4 (strongly agree). The means, each posed in a negative connotation, of both groups ranged from 1.47 to 2. The means on the other two statements, each posed in a positive connotation, of both groups ranged from 2.97 to 3.28.

Discussion

The impact that scholarships related to teaching have on recruiting and retaining high-quality teachers in high-need schools is unclear. This is also true of the Robert Noyce Teaching Scholarship. Some research exists on factors that influence Noyce Scholars' decision to enter the teaching profession and how the financial incentive of the scholarship impacted their decision to teach (Bull et al., 1994; Darling-Hammond, 2007; Liou, Desjardins, & Lawrenz, 2010; Liou & Lawrenz, 2011; Henry et al., 2012) but little research can be found on characteristics special to Noyce Scholars. If some profiling of the Noyce Scholar can be done, then universities can use the information during the recruiting and preparation phase to improve teaching and teacher preparation.

In this study, four categories were analyzed to investigate the perceptions and characteristics of Noyce Scholars about teaching and the teaching profession. The four categories were Decisions on Becoming a STEM Teacher (DBST), Plans for Graduate Education (PGE), Teacher Preparation (TP), and School Climate and Teacher Attitudes (SCTA). To aid in identifying any perceptions and characteristics unique to Noyce Scholars across these categories, data was compared to a group of non-Noyce Scholars who received their teacher training from the same teacher preparation program. Non-parametric inferential statistics used on the data indicated some significant differences between groups across three of the four categories.

In the DBST and PGE categories, the results indicate that differences between Noyce Scholars and non-Noyce Scholars do exist. The Noyce Scholars, in general, made decisions about their future plans at younger ages and for different reasons than the non-Noyce Scholars. Significantly more Noyce Scholars decided to become teachers before the age of 18 than non-Noyce Scholars and external factors like flexibility or autonomy of STEM teaching and conduciveness to family life seemed to be less of an influence on their decisions to teach. This suggests that during their high school years, Noyce Scholars are actively thinking about their future careers; they are early career deciders. Noyce Scholars may be giving more weight to reasons like "love of a subject" and "making a difference in the world" than reasons like "flexibility or autonomy of STEM teaching" and "conduciveness to family life" for deciding to be a teacher. Noyce Scholars appear to be less influenced

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during their college-aged years on making a career choice since many of them made the decision before 18. Non-Noyce Scholars, on the other hand, seem to enter college undecided on a career choice and maybe more influenced by external factors when choosing a career. Thus, when recruiting teachers into the profession during the college years, external factors like "flexibility or autonomy of STEM teaching" and "conduciveness to family life" may be good aspects of the teaching profession to highlight to recruit college students into the teaching profession or have them consider teaching as a career.

Results in the PGE category also indicate that Noyce Scholars decide to invest in their graduate education at a higher rate than their non-Noyce counterparts. This could be due, in part, to the funds that the Noyce Scholars received as undergraduates or that Noyce Scholars were academically successful students. Receiving the scholarship funds as an undergraduate could have put the Noyce Scholars in a position where they had less student loan debt and thus, more willingness to invest money in graduate studies. This notion cannot be fully supported by the results of this study, but it is something that could be explored in future studies. Additionally, Noyce Scholars were required to have a 3.0 grade point average to be eligible for the scholarship. This prerequisite condition for the scholarship may play a role in the motivation for Noyce Scholars to seek more graduate education than the non-Noyce Scholars. Nonetheless, this supports the notion that Noyce Scholars make decisions about their future earlier than the non-Noyce Scholars.

Results in the TP category indicate that there are few differences between groups regarding the participants' perceptions of their preparedness for 1st year of teaching and the opportunities with the teacher preparation program. This is not surprising because all participants in the study were similarly trained. The opportunity to interact with children from difference cultures showed Noyce Scholars reporting more opportunity to interact with children from different cultures during their teacher preparation than non-Noyce Scholars. Again, this is not surprising because of the structure of the program. Noyce Scholars were required to tutor, mentor, or assist with groups of children that came from the lower socioeconomic sub-groupings.

Results in the SCTA category imply little difference between groups regarding the participants' perceptions on school climate and teacher attitudes. There was only one statistically significant difference between groups and that was in the type of school (high-needs or not) in which the participants were employed. This finding, however, is not surprising given that Noyce Scholars agreed to teach in a high-needs school district when they accept the Noyce Teaching Scholarship. Thus, this finding seems to be influenced by the requirements of the Noyce Scholarship program and is also in align with current research on scholarship programs; the financial incentive has the most influence on recruiting teachers to high-need schools.

Though there is little difference among groups in the SCTA category, the results of the analysis do indicate that the overall perception of the participants regarding school climate and teacher attitudes is fairly positive. Most of the participants expressed a desire to stay in the profession and also indicated they would choose to teach again given the opportunity to start their college days over. The lowest scores were in the Teacher Influence Over School Policy, indicating that participants had minor to moderate influence over school policy. Further research could investigate relationships between teachers' attitudes toward the profession and their perceived influence over school policy. Future studies could also try to include greater incentives for participating in the study in order to obtain a more representative sample.

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Appendix A

Descriptive Statistics and Results from Mann-Whitney U Test for the Question "Which of theses were part of your experience in your teacher certification program?".

Question	Noyce		Non-Noyce		Mean	
	Mean	*SD*	Mean	*SD*	Diff	M-W U
Opportunities to interact with adults from different cultures	1.45	0.506	1.38	0.492	0.07	0.564
Opportunities to interact with children from different cultures	1.34	0.484	1.12	0.336	0.22	0.043*
Education about different cultures	1.28	0.455	1.16	0.369	0.12	0.259
Class(es) in teaching methods specific to your subject area (e.g., science or math)	1.03	0.186	1.09	0.296	-0.06	0.354
Education about how to work in high needs schools specifically	1.52	0.509	1.66	0.483	-0.14	0.274
Opportunities to observe/work at high needs schools (not student teaching)	1.21	0.412	1.25	0.44	-0.04	0.692
Student teaching experience	1.1	0.31	1.06	0.246	0.04	0.564
Student teaching experience in a high needs school	1.52	0.509	1.66	0.483	-0.14	0.274
A guaranteed job (assuming successful completion of program) at a participating school district	1.83	0.384	1.84	0.369	-0.01	0.866
Mentoring experiences provided by your certification program during your first year of teaching	1.72	0.455	1.69	0.471	0.03	0.756
Mentoring experiences provided by your district during your first year of teaching	1.24	0.435	1.16	0.369	0.08	0.407
Mentoring experiences provided by your certification program during your second year of teaching	1.79	0.412	1.84	0.369	-0.05	0.610
Mentoring experiences provided by your district during your second year of teaching	1.76	0.435	1.72	0.457	0.04	0.726
Continuing contact with participants in your teacher education program	1.72	0.455	1.53	0.507	0.19	0.124

Appendix B

Descriptive Statistics and results of Mann-Whitney U test for question "To what extent do you agree or disagree with each of the following statements?".

Statements	Noyce		Non-Noyce		Mean	
	Mean	*SD*	Mean	*SD*	Diff.	M-W U
The school administration's behavior toward the staff is supportive and encouraging.	3.38	0.775	3.16	0.92	0.22	0.298
I am satisfied with my salary.	2.93	0.842	2.78	0.941	0.15	0.525
The level of student misbehavior in this school (such as-noise, horseplay or fighting in the galls, cafeteria, or student lounge) interferes with my teaching.	2.10	1.145	1.78	0.906	0.32	0.348
I receive a great deal of support from parents for the work I do.	2.55	0.870	2.62	1.008	0.22	0.690
Necessary materials such as textbooks, supplies, and copy machines are available as needed by the staff.	3.31	0.806	3.28	0.813	0.03	0.823
Routine duties and paperwork interfere with my job of teaching.	2.72	0.96	2.44	1.014	0.28	0.324
My principal enforces school rules for student conduct and backs me up when I need it.	3.0	0.756	3.0	1.107	0	0.549
Teachers in this school consistently enforce rules for student behavior, even for students who are not in their classes.	2.45	0.827	2.47	0.983	-0.02	0.860
Most of my colleagues share my beliefs and values about what the central mission of the school should be.	3.03	0.823	2.84	0.847	0.19	0.261
The principal knows what kind of school he or she wants and has communicated it to the staff.	3.17	0.759	3.03	1.062	0.14	0.894
There is a great deal of cooperative efforts among staff members.	3.21	0.62	3.13	0.942	0.08	0.911
In this school, staff members are recognized for a job well done.	3.24	0.786	2.94	0.840	0.30	0.118
I worry about the security of my job because of the performance of my students or my school on state and/or local tests.	1.38	0.561	1.47	0.879	-0.09	0.933
State or district content standards have had a positive influence on my satisfaction with teaching.	1.93	1.033	2.16	1.051	-0.23	0.441
I am given the support I need to teach students with special needs.	2.66	1.111	2.59	1.103	0.07	0.712
The amount of student tardiness and class cutting in this school interferes with my teaching.	2.17	1.037	2.03	1.092	0.14	0.804
I am generally satisfied with being a teacher at this school.	3.45	0.910	3.37	0.871	0.08	0.561
I make a conscious effort to coordinate the content of my courses with that of other teachers.	3.07	0.998	3.13	0.942	-0.06	0.852

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RESEARCH REPORT

A Highly Structured Collaborative STEAM Program: Enacting a Professional Development Framework

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Abstract: *This paper reports on a highly-structured Mathematics-Science Partnership (MSP) professional development (PD) program focused on the integration of science, technology, engineering, arts, and mathematics (STEAM) in elementary mathematics and science. With a support system including higher education STEAM education and content faculty, community informal learning partners, an external evaluation team, school administrators, and expert STEAM teachers, twenty-five teachers and five STEAM instructional coaches met together for whole-group PD as they developed and then implemented integrated STEAM problem-based inquiries in their classrooms. This paper describes how the PrimeD framework (Rakes, Bush, Ronau, Mohr-Schroeder, & Saderholm, 2017; Saderholm, Ronau, Rakes, Bush, & Mohr-Schroeder, 2017) guided the STEAM PD program through a collaborative and reflective process. .*

Keywords: Professional development, STEAM, science education, mathematics education, frameworks

A Highly Structured Collaborative STEAM Program: Enacting a Professional Development Framework

This paper presents a case study of the enactment of the Professional Development: Research, IMplementation and Evaluation (PrimeD; Rakes, Bush, Ronau, Mohr-Schroeder, & Saderholm, 2017; Saderholm, Ronau, Rakes, Bush, & Mohr-Schroeder, 2017), framework to guide a Science, Technology, Engineering, Arts, and Mathematics (STEAM) PD program through a collaborative and reflective process.

Background

The importance of integrating science, technology, engineering, and mathematics (STEM) is well recognized. Some proponents (e.g., U.S. Department of Education, 2015) focus on future job opportunities, noting that integrated STEM jobs (e.g., biomedical engineer) are projected to increase at more than double the rate of jobs in non-integrated STEM fields (e.g., mathematician). Others (e.g., Hom, 2014) focus on how the integration component of STEM improves the quality of learning. The addition of the "A" ("arts") to make "STEAM" is relatively new and recognizes the importance of the role of beauty, creativity, aesthetics, and emotion in the solution of a problem (Bailey, 2016). Peppler (2013) and Smith and Paré (2016) pointed out that

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incorporating the arts in STEM education provides a much-needed affective connection for difficult-to-grasp concepts. For students to fully realize the benefits of STEAM education, teachers need to understand both the individual disciplines and how they fit together. Cook (2016) pointed out that such preparation is not part of typical teacher PD. PD that focuses on STEAM therefore offers unique potential to improve student learning outcomes.

STEAM PD is most likely to meet its fullest potential when it is characterized by a number of elements that have been well-studied and defined. These elements are categorized in PrimeD (Rakes et al., 2017; Saderholm et al., 2017) as "elements of effective PD", that is, having an actual impact on classroom practice. Long-term PD iteratively connected to classroom practice can be challenging and complex but essential to creating real change in classrooms (Desimone, 2009; Loucks-Horsley, Stiles, Mundry, Love, & Hewson 2010; McAleer, 2008; Sztajn, 2011). PD that has a well-planned classroom implementation component can alter teachers' practice by impacting teachers' knowledge and skills through the actual practice of teaching (e.g., Borko, 2004; Greeno, Collins, & Resnick, 1996; Lave & Wenger, 1991).

Review of Literature on Effective Professional Development

First, we consider effective PD broadly. Guskey (2000) and Loucks-Horsley et al. (2010) posited that the foundation of effective PD is the improvement of student learning by improving teachers' knowledge, skills, attitudes, and practices. Traditionally, teacher PD has often been conducted in ways that are disconnected from classroom practice (workshop style, as in Darling-Hammond & Richardson, 2009) and as a result, has little long-term impact on classroom instruction. Putnam and Borko (2000) noted that teacher learning should be situated within a context. When teacher learning is "situated," the teacher is altering their practice in alignment to the PD, thus changing and growing their knowledge and skills of the teaching practice (as in Borko, 2004; Greeno et al., 1996; Lave & Wenger, 1991). As teachers' knowledge and skills improve, they bring a different knowledge and skill level back to the PD sessions, thus improving the effectiveness of the PD itself, creating a synergistic cycle from PD sessions, through teachers' practice in the classroom, and back to PD sessions. PD conducted in this way creates a co-constructed environment in which teachers collaborate with the PD leadership team to create a learning experience that connects directly to their classroom needs and practice. This design structure creates a PD experience different from traditional PD that typically situates teachers primarily as participants, not as leaders (Timperley, 2011).

When considering more specific aspects that makes for effective PD, Borko (2004) contended there are four elements that must be examined when researching a PD program: the teacher participants in the PD program, the PD program itself, the facilitators, and the context in which the PD program and its participants function. Garet, Porter, Desimone, Birman, and Yoon (2001) identified structural (i.e. organizational) and core (i.e. substance) features of PD. Structural features consisted of the organization of activities during the PD, duration of the PD, degree of participants' collective participation (that is, rather than teachers participating in isolation). Core features consisted of the focus of the PD; level of integrated learning; plan for classroom implementation; review of student work; opportunities for participant presenting, leading, and writing; connections to goals and between activities; communication with others; and alignment to district and/or state standards and key assessments, which also aligns to the work of Darling-Hammond (1997) and Liberman (1996). Garet et al. (2001) found PD that occurred over a longer period of time, even for multiple-years, provided more opportunities for connections to classroom practice and that longer PD fostered coherence to goals, teaching experiences, and impacted teachers' content knowledge. While Garet et al. (2001) reported a positive relationship between content knowledge and changes in teaching practice, Cohen and Hill (2000) and Kennedy (1998) noted that when PD is content specific (rather than focused on general strategies), student achievement is more likely to show improvement.

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Collective participation and coherence are two aspects of PD that are often found to be instrumental in its effectiveness (Desimone, 2009). Collective participation is the engagement of multiple participants from the same community (e.g., school, district) during the PD program (National Institute for Excellence in Teaching, 2014). Coherence addresses how well the PD program aligns with other areas of teacher participants' daily tasks, expectations, and needs. PD programs that have coherence are more likely to bridge the gap between PD and classroom practice by providing time for teacher participants to plan and receive technical support – which has been found to have a strong connection to the knowledge and skills under study in the PD being implemented into the classroom (Penuel, Fishman, Yamaguchi, and Gallagher, 2007).

In summary, PD that is content-specific, aligned to clear program goals, extended over time, connected to classrooms, situated in teachers' context, and includes teachers as collaborators, co-developers and co-decision-makers of the PD has the potential to be the most effective (as described in Desimone, 2009; Loucks-Horsley et al., 2010; McAleer, 2008; and Sztajn, 2011). The PrimeD framework (Rakes et al., 2017; Saderholm et al., 2017) was designed to provide a structure to PD programs in a way that fosters these characteristics of effectiveness.

In this case study of enacting the PrimeD framework in a STEAM PD program, the two research questions were:

1. How was each of the four phases of PrimeD enacted in a STEAM PD program?
2. How did enacting PrimeD guide the PD providers in reflecting on the PD program across the four phases?

The sections that follow introduce, describe, and demonstrate the enactment of PrimeD in a STEAM-focused PD program.

PrimeD: A PD Framework

The work shared in this paper stems from a larger research project in which a core team of five researchers are currently working to enact PrimeD across multiple PD programs. This paper shares the journey of one of these programs, funded by a Mathematics Science Partnership (MSP) grant, Full STEAM Ahead: Preparing Elementary Teachers to Implement Best-Practices in Integrated STEAM Instruction, providing a case study in enacting PrimeD in a STEAM PD program. We specifically chose to showcase this program as all five core members of the research team were closely involved, making it ideal for describing a full enactment of PrimeD from conception to culmination.

PrimeD (Figure 1) structures PD into four phases: Design and Development (Phase I), Implementation (Phase II), Evaluation (Phase III), and Research (Phase IV). These four phases work together to guide and provide feedback to stakeholders throughout the duration of the PD program. PrimeD was designed to inform the reflective process within and between stakeholders and challenge them to explicitly consider all components of the framework throughout the duration of the PD program. We provide an overview of the four phases below. For even more in-depth information on the synthesis of literature and creation of PrimeD, see Rakes et al. (2017) and Saderholm et al. (2017).

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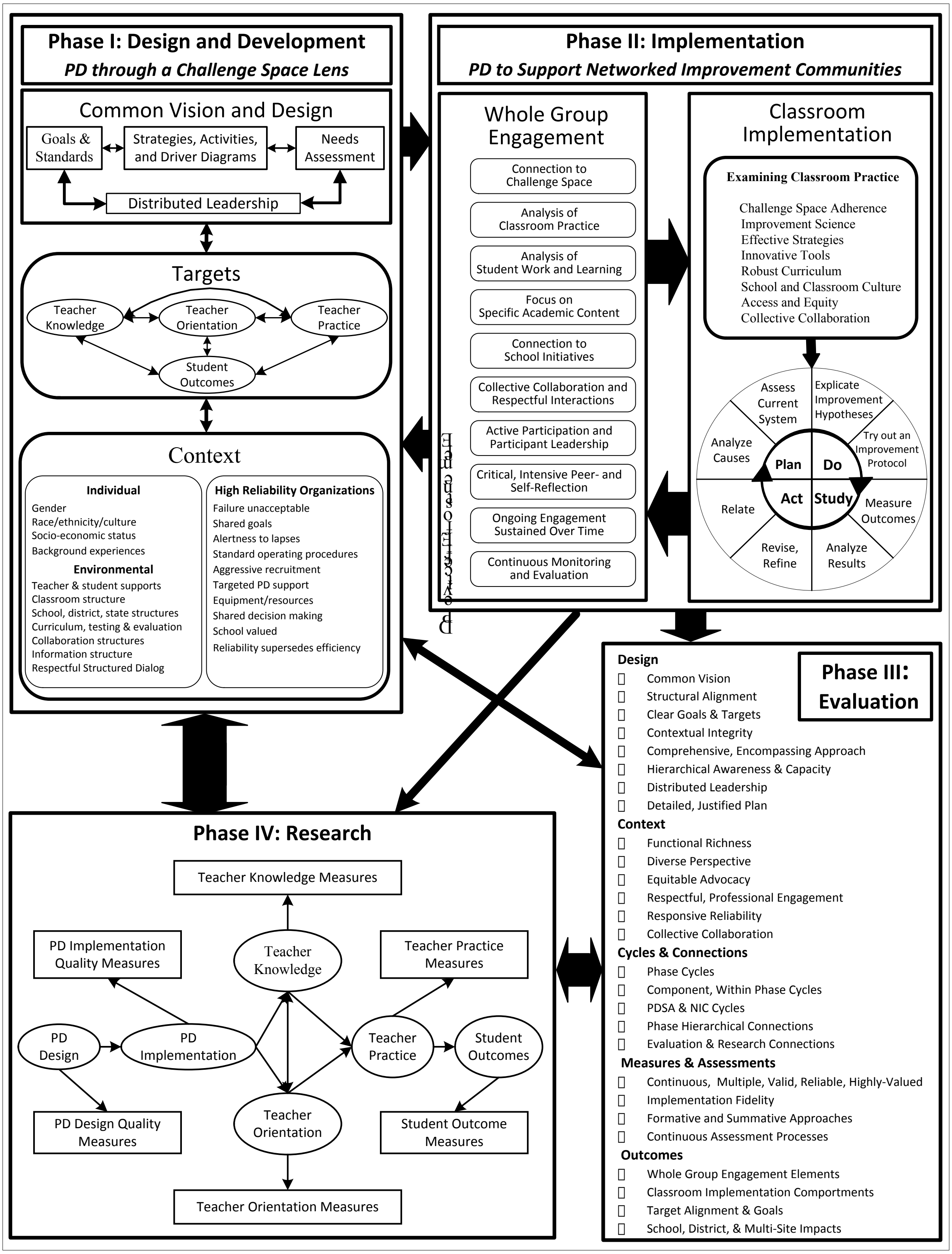

Figure 1. *Professional Development: Research, IMplementation, and Evaluation framework (PrimeD; updated from Rakes et al., 2017; Saderholm et al., 2017).*

In Phase I, a challenge space (Bryk, Gomez, & Grunow, 2010) is developed to describe a central focus, problems to be solved, target outcomes, strategies for meeting the challenges, and methods for assessing progress toward meeting the challenges. Identified strategies should consider elements of effective PD outlined in Phase II of PrimeD. Most importantly, Phase I pushes PD program providers to come together with all stakeholders involved (including teacher participants) to develop and articulate a common vision for the PD program that addresses school and classroom needs. PrimeD showcases the need for interconnectedness between common vision and design, targets, and context, as each are closely related to desired outcomes. While not intended to be exhaustive, Phase I illustrates the importance of intentionality and explicitness in determining and planning for what will or will not be addressed in the PD program. Although a single PD program may not address all components listed in PrimeD, a goal for Phase I is that whatever is not addressed is done so purposefully.

Phase II focuses on the implementation of the PD program and is divided into two components, whole group engagement and classroom implementation, with teachers intentionally engaged as partners rather than only recipients. The whole group engagement component of Phase II synthesizes key elements of effective PD (e.g., Borko, 2004; Desimone, 2009; Greeno et al., 1996; Lave & Wenger, 1991; Loucks-Horsley et al., 2010; McAleer, 2008; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Putnam & Borko, 2000; Sztajn, 2011; Timperley, 2011). Providing a specific example, Desimone (2009), Loucks-Horsley et al. (2010), McAleer (2008), and Sztajn (2011) all defined elements of effective PD as (a) directly and explicitly connected with identified student learning needs; (b) intensive, sustained, and directly connected to practice; (c) specific content focused; (d) aligned to current school initiatives; (e) providing opportunities for teachers to collaborate with one another and build productive working relationships; and (f) continuously evaluated. In addition to whole group engagement, where teachers and other participants (such as instructional coaches or administrators) attend PD sessions, Phase II highlights classroom implementation of practices and strategies from the whole group engagement sessions as an equally important component of PD implementation, providing meaningful opportunities for teachers to develop, practice, and reflect on their practice in their natural teaching environment (as recommended by Philippou et al., 2015; Steyn, 2015; Timperley, 2011). To structure the classroom implementation component, teachers use Plan-Do-Study-Act (PDSA) cycles (Bryk et al., 2010; Martin & Gobstein, 2015) to carry out trials of change ideas in their classrooms. Using PDSA cycles empowers teachers as researchers of their own classrooms. Over time, the implementation and refinement of a series of PDSA cycles become a results-driven innovation engine not only for that individual teacher, but for others in the PD program. This connection of whole group engagement to classroom implementation has been consistently shown as critical for connections between the PD sessions and participants' ongoing classroom practice to be realized (e.g., Hiebert & Stigler, 2000; Hiebert et al., 2005; Jones & O'Brien, 2014; Philippou et al., 2015; Sabah, Fayez, Alshamrani, & Mansour, 2014; Timperley, 2011). As participants enact PDSA cycles, they return to the whole group engagement PD sessions and engage in reflecting, troubleshooting, and planning with fellow participants. Collaborative activities such as peer observations and analysis of student work samples are used to improve teacher practice and subsequently, student achievement (as advocated for in Darling-Hammond & Richardson, 2009).

Phase III is dedicated to the evaluation of Phases I and II both formatively and summatively. Ideally, iterative evaluation throughout Phases I and II should provide formative support to PD program providers in addition to the more commonly practiced summative evaluation. Evaluation of Phase I should examine the degree of comprehensiveness and clarity of the challenge space as well as how the challenge space is understood and applied by all stakeholders throughout the PD program. Another key tenet is that PD design should be considered dynamic and can and should be adjusted along the way according to evaluation results. For example, when difficulties and obstacles arise, evaluation can objectively examine how they were used to refine the goals, targets, and strategies or to better understand nuances within the challenge space. Evaluation of Phase II should focus on how well the whole group engagement consistently includes the identified elements of effective PD and the extent to which classroom implementation is connected to whole group engagement. Before evaluation leads to changes in Phase II, PD providers should first consider how potential changes are related to the challenge space (i.e., one-way arrow from Phase II to III in Figure 1). By making design changes

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through Phase I and involving all stakeholders, including participants, in such decisions, modifications can become systemic and will filter to Phase II with a higher level of stakeholder support and influence greater fidelity as everyone is on the same page.

Phase IV (research) is interrelated yet distinct from Phase III (evaluation), as noted by Chyung (2015). Both evaluation and research involve investigation and inquiry, similar methods, and some of the same data sources. However, evaluation is generally context-specific whereas research tends to seek generalizability (Chyung, 2015). More specifically, evaluation questions examine how well program outcomes are met whereas research questions examine possible factors that may have influenced why outcomes were reached or not reached. For example, evaluation of Phase II might address how well whole group engagement included the elements of effective PD while research might instead investigate which of those elements had the greatest potential for impacting classroom practice.

PD programs that address the effective elements of PD described above are complex and difficult, therefore, a conceptual framework, such as PrimeD, is needed to guide PD providers' process of designing and developing, implementing, evaluating, and researching the effectiveness of their PD programs in efforts to guide widespread and systematic improvement in the perception and effectiveness of PD (Rakes et al., 2017; Saderholm et al., 2017).

Methodology

The methodology used for this study was a single case study (Yin, 2017), where enacting PrimeD in one in-service PD program was considered the case. Because a case study examines data sources in an effort to support or refute propositions (or theories) to advance those ideas, we identified initial propositions from PrimeD. We then examined our data with those ideas in mind.

Description of the Case

Our integrated STEAM PD program drew on two reform models: problem-based inquiry, shown to increase urban and minority students' achievement and engagement in mathematics and science (Buck, Cook, Quigley, Eastwood, & Lucas, 2009); and interdisciplinary learning, also shown to enhance learning outcomes and engagement in mathematics and science (Czerniek, 2007). Our partner school district was a large urban district in the Midwest classified as a "Needs Improvement/Progressing" district with a state-level percentile rank of 51. The district ranked below the state average in grades K-5 mathematics and science achievement (based on the state standardized assessment). Working with district leadership, we identified five elementary schools to participate in the PD program, one of which was a new school. Each of the five elementary schools were in the beginning stages of conceptualizing STEM/STEAM initiatives as a strategy for increasing science and mathematics achievement. After the five schools were identified, principals and district leadership recruited grades 3-5 teachers at each school. Additionally, one instructional coach or STEM/STEAM lab teacher at each school was recruited as the STEAM coach for that school. Therefore, each of the five schools had one STEAM coach and a group of teachers (between 2 and 9 depending on the school) as participants. While the PD program focused on grades 3-5, one second grade teacher and one special education teacher participated at request of the district leadership. Program participants were 25 classroom teachers and 5 STEAM instructional coaches. Teachers' classroom teaching experience ranged from two to more than 20 years. Their educational attainment ranged from a bachelor's degree to multiple graduate degrees primarily in education (not in the content areas of mathematics or science). No teacher or STEAM instructional coach participant held a terminal degree.

Key stakeholders in the PD program included local non-profit informal learning education partners, the building administrators from the five schools and district administrators, an expert STEM lab teacher, an expert STEAM lab teacher, a STEM center founder who served as a consultant, and higher education faculty in science, mathematics, and education. The PD program spanned two academic years (October through April each year) with bi-monthly whole group engagement PD sessions, ongoing school-level Professional Learning Communities (PLCs), and ongoing classroom implementation. Overall, teachers attended approximately 30 whole group PD sessions over the two academic years, some occurring during the school day from 8:30 a.m. -3:30 p.m. and others in the evening from 5:00 p.m. - 8:30 p.m., for a total of 130 hours of PD. The PD program also included nine hours of initial training for the STEAM coach at each school as they were responsible for leading the STEAM PLC for participating teachers in their building. Peer observation and feedback were built into the core structure of the PD program. At the end of each year, STEAM coaches and teachers (and some of their students) from the five participating schools as well as our informal learning partners hosted a free public community "Maker" event. PD program goals included 1) increase students' science and mathematics achievement; 2) increase teachers' and coaches' mathematics and science pedagogical content knowledge; and 3) build a community of educators dedicated to integrated STEAM teaching and learning.

Data Collection and Analysis

Throughout the two-year duration of the PD program, data were amassed that included teacher-level, student-level, and administrator-level data specific to the three project goals described above. For purposes of this single case analysis, multiple sources of qualitative data (Creswell, 2009) were most relevant to the research questions. These data included videos of whole group PD sessions, document analysis of artifacts including STEAM inquiry planning documents, teacher lesson reflections, student work samples, emails between facilitators and instructional coaches and facilitators and the external evaluation team, iterative qualitative feedback from external evaluators, and unstructured individual and group conversations. These documents were triangulated to inform the data analysis for this study.

To guide the data analysis, a priori propositions under study came directly from components in PrimeD including 1) common vision and design, 2) targets, 3) context, 4) whole group engagement, 5) classroom implementation, 6) evaluation, and 7) research. These propositions enabled us to determine ways in which using the PrimeD framework guided us as PD providers or fell short. As a research team (PD providers and external evaluators), we conducted a SWOT (strengths, weaknesses, opportunities, threats) analysis for each proposition. For each of our seven propositions, data were triangulated to gain a holistic sense of how PrimeD helped (or did not help) navigate a specific component of the PD. Major themes and patterns emerged from the triangulation of data for each proposition. For example, with regard to the critical and intensive peer and self-reflection component of whole group engagement, we triangulated the following data: the PD providers' in-the-moment noticings, external evaluation team meeting notes, observation instruments completed by the external evaluation team, and document analysis of reflections by teachers. This revealed that the critical and intensive peer and self-reflection component was underdeveloped. We were also attentive to external factors that may have influenced each proposition beyond PrimeD, such as other demands placed on teachers by the district, conflicting school initiatives and testing pressure, and teacher preconceptions and buy-in regarding the PD program.

Several methods were used to enhance the trustworthiness of the findings. The triangulation of qualitative data sources required themes to be the result of multiple forms of evidence (Patton, 2002). The external evaluation team provided peer debriefing throughout the PD program through written feedback and acting as a sounding board for ideas as recommended by Creswell and Miller (2000). Every PD session was analyzed by the facilitators and the external evaluation team for emergent themes (i.e., prolonged engagement; Lincoln & Guba, 1985) and to provide feedback on implementation of PrimeD (i.e., persistent observation; Lincoln & Guba, 1985).

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Results

This case study examined the enactment of PrimeD in a STEAM PD program. The two research questions prompted an examination of how all four phases of PrimeD were enacted in the STEAM PD and how that enactment guided the PD. Results are structured by examining each research question for each phase of PrimeD.

Phase I: Design and Development

Research question 1. Our design and development work began approximately six months prior to the start of the PD program through initial conversations with the mathematics and science district specialists at our partner school district. In collaboration with these district content specialists, we developed a vision that met the needs of the district and teachers, was grounded in research-based best practices in both PD effectiveness as well as teacher pedagogy and content development in mathematics and science education, and which were aligned to our three project goals (see description of case above). By learning about and understanding the governance structures of the district, we were able to determine the best methods for communicating with district and building administration, STEAM instructional coaches and teachers, and the district research and evaluation team.

Our PD program focused on mathematics and science taught in grades three to five as outlined in the Common Core State Standards for Mathematics (CCSSM; NGA Center for Best Practices & CCSSO, 2010) and Next Generation Science Standards (NGSS Lead States, 2013) content and practices. The district's research and evaluation team provided summary data from district quarterly assessments. Each of the items in the quarterly assessment were aligned to clusters of grade-level CCSSM content standards. For our participating schools, we were able to identify the clusters in which students struggled the most. This information served as part of our program needs assessment and helped us tailor the PD to areas needing the most support. We aligned these identified mathematics achievement gaps to science content and practices to ensure we were also addressing students' science learning and achievement. Through this collaboration, we decided to measure student achievement through both the state standardized assessment as well as district quarterly assessments called "proficiencies."

Each participating school was selected because they were in the beginning stages of conceptualizing school-wide STEM or STEAM programs as an avenue to increase mathematics and science achievement. With the use of one STEAM coach in each of the five schools to lead school-level STEAM PLCs and to help facilitate the classroom implementation portion of the PD, our program was strategically designed to build school-level capacity in terms of teacher leadership, infrastructure, and materials/resources. Teacher support included close partnerships with community stakeholders (e.g., a local state science center, center for performing arts, and an art museum), direct involvement by school and district administrators, a STEM center founder who served as a consultant, an external evaluator who specialized in mathematics education and research design (and his team), an expert K-5 STEM lab teacher with over 20 years teaching experience who is also a national Engineering is Elementary PD facilitator, an expert K-5 STEAM lab teacher with over 10 years teaching experience who has received multiple teaching awards and recognitions, and two higher education faculty in science and mathematics to serve as content experts. The key investigators, who were also the lead facilitators on the project, were a mathematics teacher educator and science teacher educator interested in the effectiveness of integrated STEAM instruction.

The STEAM coaches and district content specialists were instrumental in ensuring the PD program was tightly connected to district demands (i.e., curriculum maps, standards, and assessments), centered on the needs of local students (i.e., interests and available supports), and aligned to related initiatives in the district (i.e., district-developed curricula and existing resources). An unexpected outcome of this close partnership was the impact on a district-level content coach. Because of their experience with PrimeD, this coach made changes to district PD by explicitly including an interdisciplinary content focus rather than only a pedagogical focus as had been done in the past. Reciprocally, this same coach has helped us understand the organization of the district science curriculum maps and the constraints and schedule by which the teachers must adhere. Working collaboratively with school district leadership in year two of the project uniquely helped to prepare participants as our state released a completely revamped science standardized assessment. This assessment occurred during year two of our PD program and we adapted program PD plans to meet this timely need for our participants. Also, in year two, district specialists were more involved in our whole group engagement PD sessions, and having their expertise as well as a district lens to statewide assessments served as a great asset.

Research question 2. We found that being transparent and explicit about our vision and program decisions was a key strategy to support collaborative and reflective efforts in Phase I. We shared and discussed the PrimeD framework with our STEAM coaches, partners, and leadership team, and subsequently with teachers. Figure 2 showcases sample handwritten notes aligned to Phase I used to focus our conversations. We found it extremely helpful to have the STEAM instructional coaches as a key part of these conversations in part because district leaders had the opportunity to share a dialogue about the program. For example, at one such meeting, a district-level administrator stated that:

> This project aligns to the focus on STEAM that was evident at a federal Title II conference I recently attended in DC. This work is valued nationally and is positioning us as innovative leaders in STEAM. Your (the coaches) collaborative leadership will guide us in sustaining this project long-term. (District Leader, MSP Meeting, 2016)

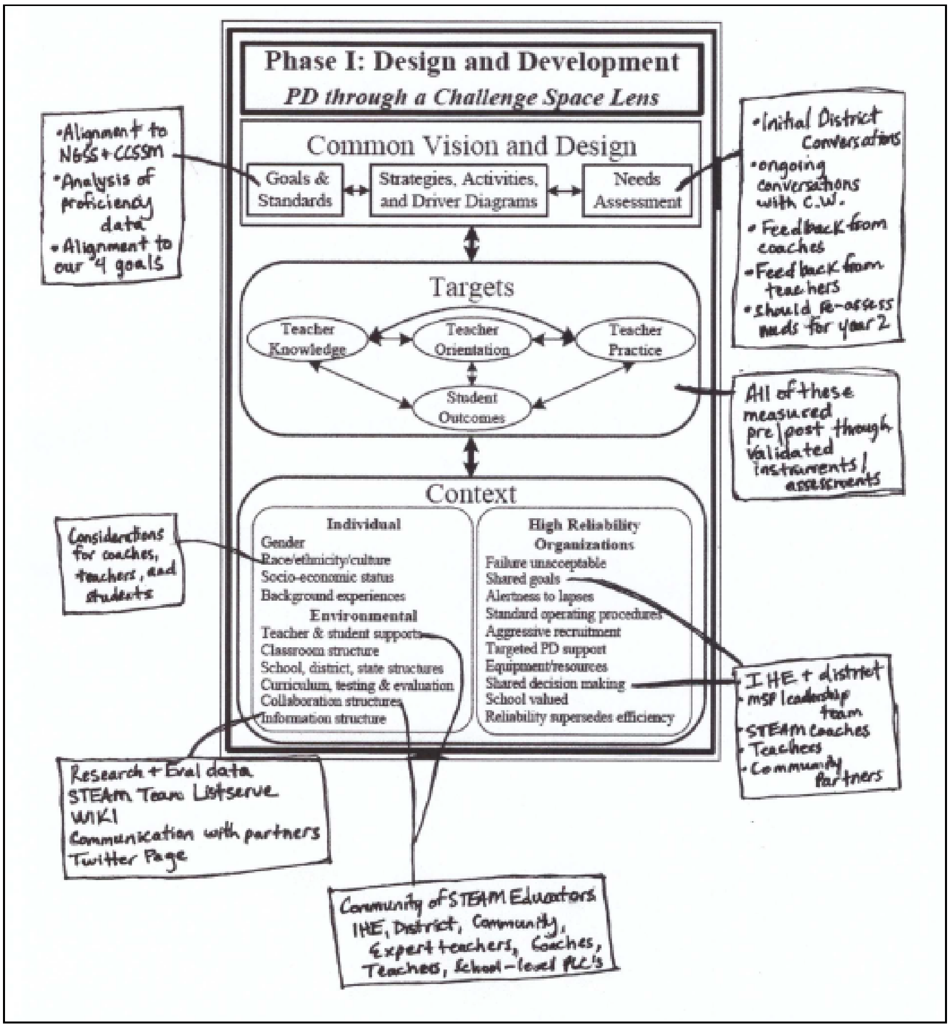

Figure 2. *Phase I notes*

The PrimeD framework served as a springboard to launch and manage difficult conversations about areas of concern. For example, we needed stronger communication with building principals. Explicitly holding ourselves accountable for Phase I led us to brainstorm with our external evaluator, which resulted in the addition of a monthly newsletter we began sending to building and district leadership so they could keep abreast of the innovative work of their teachers, STEAM instructional coaches, and their students. This newsletter proved to be an invaluable tool for communication and we received immediate positive responses from several building administrators.

Phase I also helped us think critically about the constructs we planned to measure (e.g., teacher knowledge, teacher orientation, teacher practices, and student outcomes). Although we had an agreement with the district regarding which student achievement measures would be collected, a misunderstanding at some schools put us at risk of missing student data. Structuring the conversation around PrimeD helped us facilitate a potentially acrimonious interaction regarding the need for the student measures to assess the quality of the PD. As a result of structured conversation aligned with the PrimeD challenge space, we were able to positively manage the situation and obtain the needed data.

Finally, as we have learned to understand and enact PrimeD more effectively, an important lesson with regards to Phase I was realized. During our initial planning time, six months prior to the official start of the PD program, only K-12 district-level mathematics and science specialists were primarily involved in collaborating with us on identifying program goals, key content to be addressed, and the general structure of the PD. It was not district protocol to invite STEAM instructional coaches and teachers (the future participants) into the initial planning process (prior to the beginning of whole group engagement PD sessions). In hindsight, doing so would have provided a different and needed viewpoint. While the STEAM instructional coaches and teachers played a large role in our planning discussions in the latter half of year one and year two, next time, we now know to advocate for their initial inclusion because such collaboration from the start would have created a more united feeling amongst the entire group. This finding aligns to the work of Jones and O'Brien (2014) who observed that PD organized from the top down (in this case, planning coming from the district level) creates a rift between the policy decision making and teachers having a voice in identifying their own PD needs. As advocated for by Philippou et al. (2015), teachers should be involved in the initial design so the PD program is best aligned with their individual schools and classrooms.

Phase II: Implementation

Research question 1. The PrimeD framework helped us make explicit and deliberate decisions regarding how the PD program would be structured (i.e., intense, on-going, connected to practice, focus on academic content, and collaborative). Moving back and forth between whole group engagement and classroom implementation is inherently complicated and challenging but is critical for situated learning (e.g., Lave & Wenger, 1991) and teacher reflection. To best connect the experience to classroom practice, the PD program took place during the academic year, from October to April. We met with teachers after school approximately twice a month and during all-day meetings four times each year.

In Phase I, we originally planned for STEAM instructional coaches from each school to organize the classroom implementation portion as well as conduct follow-up meetings with teachers to facilitate discussion and reflection. This expectation proved challenging and unrealistic because we found that the five schools were each structured quite differently. For example, some participating schools had a STEAM lab, others co-taught STEAM in their various classes, while others departmentalize to teach different components of a singular STEAM inquiry. PrimeD provided us with a research-based resource to support requests that were demanding on schools. For example, we discovered that teachers had little or no time at their schools to meet as a STEAM PLC. Consequently, we approached administrators about providing time for the STEAM PLCs to convene during the school day. We also allocated more time during our whole group engagement PD sessions to facilitate PLC work centered on reflection and analysis of student artifacts. Figure 3 showcases sample handwritten notes aligned to PrimeD Phase II used at a leadership meeting to emphasize the importance of the

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multiple components of this phase.

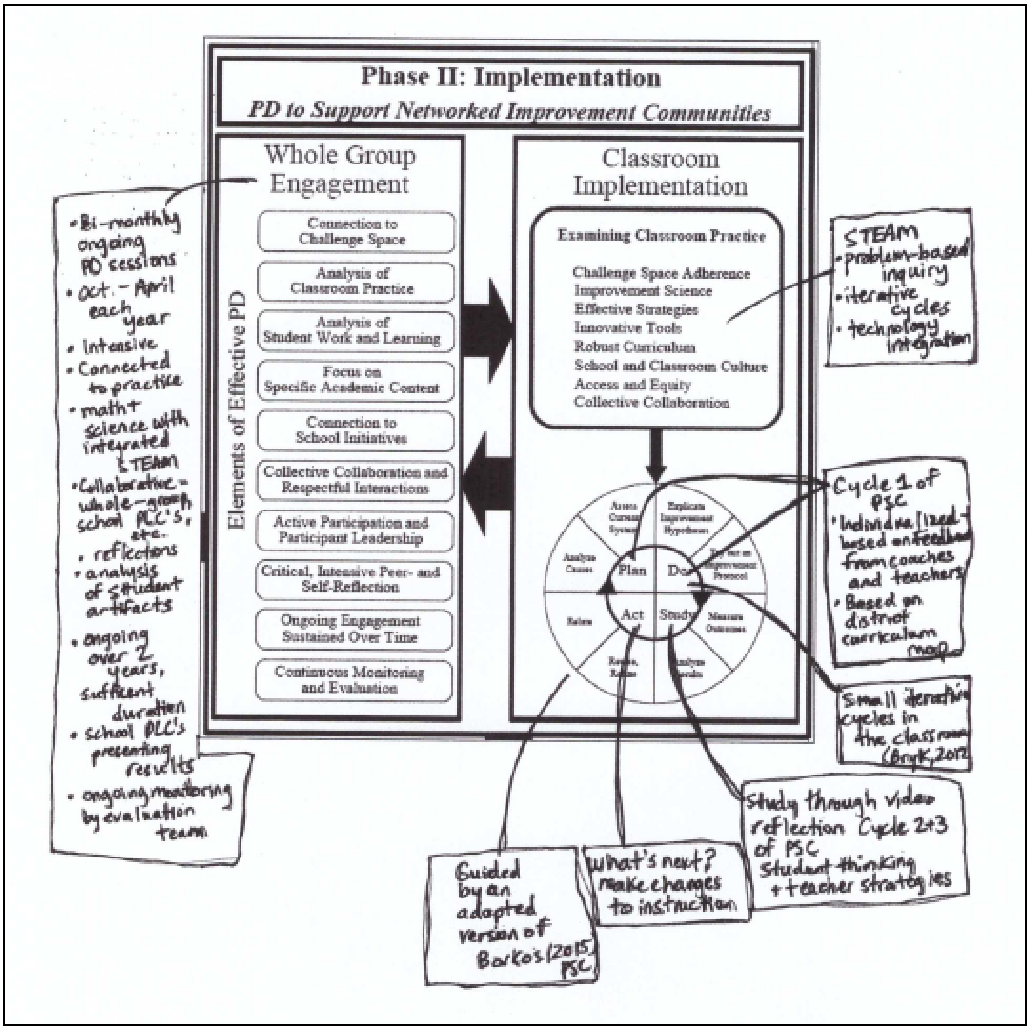

Figure 3. *Phase II notes.*

An adapted version of the Problem Solving Cycle (PSC; Borko, Jacobs, Koellner, & Swackhamer, 2015), through which we tackled the "Plan, Do, Study, Act" portion of Phase II, enabled us to support teachers' reflection of their content development and classroom implementation, essentially conducting action research. Specific prompts, used repeatedly and consistently during each PSC, centered on students' thinking and teachers' instructional moves. Because teachers undergo multiple rounds of the PSC throughout the PD program, this process has become more refined over time. Reflections target specific prompts about the mathematics and science content and practices as well as the integrated nature of the instruction. Teachers adjusted their inquiries to prepare for richer discussions with students. Teachers became more reflective on their own instructional techniques as they aimed to maximize students' mathematics and science content and practice development.

Research question 2. Collaborative reflection among the leadership team, coaches, and teachers after the first PSC revealed that teachers were attempting to emphasize too much content in their STEAM inquiries—often with the result of addressing content too broadly at the expense of depth. Therefore, during the next round of the PSC, we asked teachers to limit the content emphasis to one or two standards for each of the STEAM disciplines. For example, we encouraged teachers to avoid listing all mathematics content standards that might connect to the inquiry and select only the mathematics standard(s) most closely connected and explicitly assessed. Figure 4 showcases a comparison of one PLC's first planning document, which was more general and broad in nature, to their second planning document, which was much more specific with regards to both standards and description of students doing the mathematics and science. The collaborative reflection process promoted by PrimeD provided a structure that guided our work helping teachers articulate well-defined expectations for their inquiries and develop clear assessments that set explicit parameters and standards alignment for their STEAM explorations.

First Planning Document			**Second Planning Document**		
Content	Standard	Description	Content	Standard	Description
Science	PS3.B, ESS3.A, PS3.C, PS3.D, PS4.C	Design and create either a compass or a generator using the knowledge you have learned about magnets and electricity.	Science	**Performance Expectation:** 4.PS4.3 Generate and compare multiple solutions that use patterns to transfer information. **Disciplinary Core Ideas:** 4.PS4.A Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave and peaks). **Cross Cutting Concepts:** Patterns: (4.PS4.1) Similarities and differences in patterns can be used to sort and classify natural phenomena. (4.PS4.3) Similarities and differences in patterns can be used to sort and classify designed products.	Students will create a pattern using pattern blocks, shapes, or letters after viewing a Prezi or cryptology. Students will experiment with the energy of sound waves to move various objects. Students will demonstrate wave lengths and amplitude using ropes. Students will create a pattern (secret code) to communicate with a partner using their acquired knowledge from spy cam.
Math	4.MD.2, 4.MD.6	Solving word problems involving intervals of time, measuring angles using a protractor.	Math	**Content Standards:** (4.NF.4) Apply and extend previous understandings of multiplication to multiply a fraction by a whole number. (4.NF.5) Understand decimal notation for fractions and compare decimal fractions. **Practice Standards:** (SMP 5): Use appropriate tools strategically. (SMP 6): Attend to precision	Students will determine the number of inches of wire needed to construct a working circuit when measuring $\frac{1}{4}$ inch units. Students will determine/use the appropriate operation to acquire materials within a given budget. Students will use a ruler to measure lengths of wire to the nearest $\frac{1}{4}$ inch.

Figure 4. *Planning documents become more refined*

As teachers engaged in the classroom implementation portion of Phase II, they were highly reflective about their practice, leading to many insights. Figure 5 showcases a teacher's reflection of her students' thinking as they considered the pattern between one's height and one's length of stride during a problem-based inquiry in which students determined the number of steps it would take to walk a mile. Figure 6 highlights another teacher's in-the-moment reflection of students struggling to measure to the nearest 1/4 inch and as a result the PLC decided to conduct a mini-lesson on length measurement.

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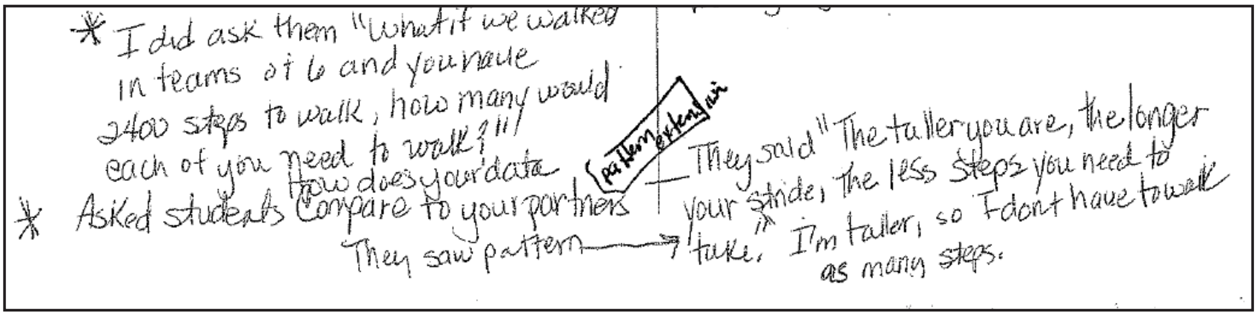
* I did ask them "What if we walked in teams of 6 and you have 2400 steps to walk, how many would each of you need to walk?"
* Asked students How does your data compare to your partners
They saw pattern → They said "The taller you are, the longer your stride, the less steps you need to take." I'm taller, so I don't have to walk as many steps.
pattern extension

Figure 5. *Teacher reflects on student generalizations on stride length.*

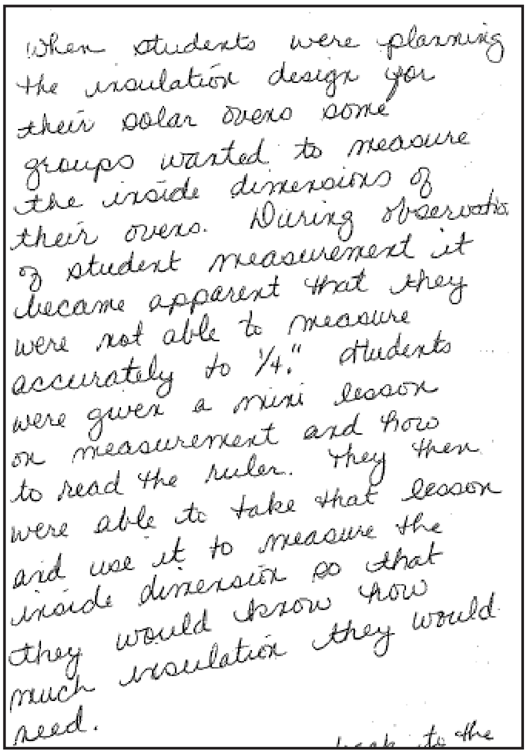
When students were planning the insulation design for their solar ovens some groups wanted to measure the inside dimensions of their ovens. During observation of student measurement it became apparent that they were not able to measure accurately to 1/4." Students were given a mini lesson on measurement and how to read the ruler. They then were able to take that lesson and use it to measure the inside dimension so that they would know how much insulation they would need.

Figure 6. *Teacher decides to revisit fractional length measurement as students wrestle with this concept.*

Individual and small group reflections were shared with the entire STEAM community during whole group engagement PD sessions. These peer-debriefings were integral to the reflective process, as teachers are asked to share their reflections on students' thinking and their own instructional moves within the context of a PSC, as well as in terms of their growth over the course of the program. Figure 7 captures dialogue on teachers' reflective nature regarding their use of questioning near the end of the first year. For example, Mary explains how the PD program has encouraged her to use probing questions to get at deep student thinking rather than to get to the correct answer. Similarly, Maria points to how STEAM teaching has helped her place more emphasis on appropriate content vocabulary. Moreover, Carrie explains that she now capitalizes on discussion of student misconceptions.

Facilitator: How has your use of questioning been challenged and changed throughout our year together? Has STEAM teaching necessitated a change in your use of questioning?

Mary: For me it has, being a new teacher, compared to how I was taught just to look for the right answer. As a first year teacher and seeing things you guys (points to other teachers) have done … I used to be like 'get the right answer and move on', but now I'm like 'so tell me why, explain that, write it down, can you show me?' So for me, it has (changed my use of questioning).

Maria: I make students use the correct vocabulary now, whereas in the past if they could just kind of explain it, I was like 'Okay, I get what you are saying.' But now I say ' I get what you are saying doesn't cut it, you have to be able to formally explain it and use the correct vocabulary.'

Annie: Something that we have worked on this year that is embedded in our STEAM teaching is that now students have to come up with the questions. It takes away from my standing up there and saying 'why do you think this happened' to their asking each other questions and engaging each other. …now it's to the point where I'm not even in the conversation. They are asking questions and having dialogue back and forth – you don't even know I'm in the room.

Jane: I think that STEAM has made my questioning more intentional and directed to students' thinking and I am more conscious of that now.

Carrie: This project has opened my eyes to having children with misconceptions explain their misconceptions and talk about it more whereas before I'd be like 'Oh, you're wrong' and I would only have the person who was correct explain.

Elizabeth: We do it in math where we say 'try to convince' and I'll play both sides of the card, and get both students to argue like we are in a courtroom. Prove your side, and I just try to stay as neutral as possible and see if anyone can be swayed and if we can come to an actual conclusion after we hear all of the arguments in the room.

Tandrea: What I've noticed in my science lab is students are having more discourse and questioning themselves and seeing that kids are taking ownership of what they understand and what they know. They even ask what is that vocabulary that we are actually talking about.

Sherry: Now I understand that if I ask a question we don't always have to answer it that class period. We can wait to tomorrow, we can let them think about it. I've always been one to say 'Okay let's get to the answer, I can't wait to tell you' but now I sit back and let them ask themselves and try to figure it out and even when they get frustrated I know that wait time is really important.

Tonya: In my world (special education teacher) it has leveled the playing field for students who come to me for half of the day. No longer does it appear that it (instruction) is different or specialized to them even though it is because I'm probing deeper for their thoughts but it's the same type of questioning for the kid sitting next to them. It's leveling the discussion.

Figure 7. *Teacher reflective dialogue on questioning.*

As we reflected on enacting Phase II of PrimeD to guide our STEAM PD whole group engagement and implementation, we shared in this section several key results regarding how PrimeD helped guide our thinking and decision making. Not all of Phase II can happen at once, but by using Phase II (and cycling back to Phase I), we were able to intentionally decide how and where to place our focus during year one. For year two, the focus of our whole group engagement shifted to Active Participant and Participant Leadership and Ongoing Engagement Sustained Over Time as we knew the importance of building capacity in each school so the impact of our program would extend beyond the scope of our funding. Our implementation focus shifted to teachers observing each other's classrooms.

Phase III: Evaluation

Research question 1. The observations of the PD program by the external evaluators were limited primarily to the whole group engagement sessions in Phase II (as well as attending selected leadership team meetings). Because PD sessions were conducted throughout the academic year, we were able to infer connections from the whole group engagement sessions to Phase I and to classroom implementation; that is, the degree to which classroom implementation artifacts drove the whole group engagement sessions during the academic years. We videotaped the whole group engagement PD sessions so that the external evaluators could review and complete an observation instrument. The lead evaluator coded some PD sessions on-site. The evaluation team used an observation instrument adapted from Horizon Research (2000) to rate the PD sessions during year one; however, ratings were at the top of the scale (4 or 5 in a 1-5 scale) for all four evaluators (i.e., restricted range threat to validity as in Shadish, Cook, & Campbell, 2002). The evaluators concluded that the Horizon instrument was developed for traditional PD, and the use of the PrimeD framework propelled the present PD program to a higher overall rating. For example, the instrument included ratings for PD culture, which included items such as "active participation of all was encouraged and valued." In traditional PD, participants are often situated as recipients of new information whereas the PrimeD framework explicitly calls for participant leadership during whole group engagement and classroom implementation. The instrument rates the frequency of indicators occurring from "Not at all" to "To a great extent." By such a rating scale, the present PD program consistently met this criterion to a great extent as rated by the PD program evaluation team. Having achieved such a benchmark, the evaluation team focused on rating the quality of the active participation, not just the frequency. In the absence of a reliable, valid instrument to rate such quality across all indicators, the team focused on providing qualitative feedback to the PD providers.

Using the PrimeD framework and the three program goals as guides, the evaluators were able to make a number of formative recommendations to the PD providers that fell into the following categories: strength of the connections to the challenge space (vision, goals, outcomes and context) and to classroom implementation, communication and networking within and among participant schools, explicit focus on content and practice standards in each PD session and in teacher-developed STEAM inquiries, sharing of leadership, responsibilities and information with PD participants, and solving problems with participants and partners.

Research question 2. The PD providers found feedback from the external evaluation team to be one of the most crucial aspects for improving their program. For example, we were challenged to place a more explicit emphasis on the mathematics and science practices, an area that needed work. We also learned we needed to ensure tighter articulation of the STEAM inquiries with the district's diagnostic and proficiency assessments. We found that PrimeD provided a structure so that the evaluation was not an add-on component but an integral part of the overall process. More than challenging us to make our measures and data collection more explicit, the evaluators helped us better understand, connect, and improve the multiple feedback cycles essential to providing an optimal PD experience for teachers. For example, we discussed with the whole group of participants how results from PD implementation informed the challenge space, and we deliberated on which specific information from the classroom implementation experience was needed to provide critical feedback to the school-level PLCs and at the same time serve as a learning experience for the whole group. The evaluation phase helped us extend the improvement cycle as an engine of change in the implementation phase to one that drives all phases of the PD program.

Phase IV: Research

Research question 1. In the current program, both internal and external evaluation focused on improving various aspects of the PD program. The research, on the other hand, focused on how PrimeD influenced the ability of participants to meet the target outcomes. For example, we researched participants' progress through enactment of PDSA cycles, analyzing the critical connection between whole group engagement sessions and classroom implementation. In year two, we piloted a classroom observation tool for participants to provide

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feedback to each other. We examined the extent to which providing this type of feedback informs and changes the observer's own classroom practice. We also examined the degree to which teachers' use of PDSA cycles improved the quality of the whole group engagement PD sessions.

Research question 2. By recognizing evaluation and research as two distinct yet interconnected phases of PrimeD and our PD program, we have distinguished what needs to be reported to conduct the evaluation to determine the effectiveness of the program while extending far beyond that to think about the deep research we wish to explore. Upon reflection, PrimeD has guided and encouraged us to explore questions beyond what we might have had we been explicitly focused on the evaluation rather than both.

Discussion

The goal of the PD in this case study was to advance teachers' ability to integrate STEAM into their classroom instruction. The use of PrimeD to structure the PD helped reach this goal. While the specific goal of this PD was unique to the integrated STEAM field, the PD program was similar to PD broadly in that it had a general goal of helping teachers improve their professional practice. We therefore assert that the benefits of PrimeD seen in this case study are transferable to PD in general. In this section, we highlight key implications this research has on teachers and PD providers.

Implications for Practice

While teachers spend a dedicated number of required (as well as often voluntary) hours every year in district and school-level PD, such PD is commonly viewed as ineffective, often due to the lack of evidence of greater teaching effectiveness (e.g., Hiebert et al., 2005). With teachers overwhelmingly viewing PD negatively and as an addition to their overflowing plate of responsibilities, the likelihood that traditional PD will have a positive, meaningful, and lasting impact on teacher professional practice is small.

PrimeD offers a structured framework as a map to systemically shift how PD programs are designed and implemented in ways that reposition teachers as leaders rather than mere participants. First, teachers themselves are engaged as active stakeholders, rather than only recipients, of the PD program. They participate in making decisions about the design and development (Phase I) as well as the implementation (Phase II) of the PD program. This change alone can address many pitfalls associated with traditional PD including applicability to classroom practice, based on teachers' needs, and teacher buy-in. Second, PrimeD provides a tool for all stakeholders (including PD providers, teachers, administrators, evaluators, etc.) to examine the PD program through an objective lens. Such objectivity allows for tough conversations to remain focused on the PD program itself and identifying possible solutions to challenges, rather than turning to unproductive conversations that might feel personal and uncomfortable. Third, PrimeD provides a coherent structure to support teachers to systematically implement strategies learned in whole group engagement PD sessions in their regular classroom instruction (through PDSA cycles). This feature is indispensable as it is a seamless component of the PD program, rather than an add-on or something extra teachers must do. Through employing a PD model in which teachers are empowered to be leaders and researchers in their own classroom, we have witnessed a renewed sense of agency that can be forceful and effective.

Implications for PD Providers

This study has important implications for PD providers (including designers, facilitators, evaluators, and researchers). First, PD providers are often assigned to develop a PD program because they are in a leadership or administrative position or because they have content or pedagogical expertise. Regardless of experience and expertise level, planning a comprehensive PD program that adheres to the effective elements of PD can be daunting, challenging, and stressful. Through this case study and our broader work, we have found that PrimeD provides a useful and much-needed structure for embarking on this complex task. PrimeD can be characterized as a roadmap that directs PD providers on where to start, what components to consider, what needs to be done,

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and how different components iteratively work together. PrimeD serves as a surface-level checklist as well as a deeper structure to guide rich considerations, tough conversations, and guidance on decisions to be made (Saderholm et al., 2017).

Second, because PrimeD synthesizes literature into a comprehensive framework and has been refined through a series of validation efforts, it can serve as a one-stop shop for all phases of a PD program (Rakes et al., 2017). For example, the elements of effective PD in Phase II compile recommendations from a wide array of literature such as Desimone (2009), Garet et al. (2001), Guskey (2000), Loucks-Horsely et al. (2010), Sztajn (2011), and Timperley (2011). PrimeD arms PD providers with a user-friendly way to justify and back their PD program decisions, needs, and requests to leadership in their school and district – which are unique to each individual context.

Conclusions

The findings from this single case study indicate that one key benefit of using PrimeD was the way in which it helped facilitate a collaborative and reflective dialogue among key investigators — a leadership team, community stakeholders, an external evaluation team, and STEAM instructional coaches and teacher participants. PrimeD inspired us to approach planning, implementing, evaluating, and researching PD in an entirely new way; one that guided us to be much more explicit and intentional in making decisions and addressing issues and roadblocks. While other high-quality PD models exist (such as Desimone, 2009; Loucks-Horsley et al., 2010), the PrimeD framework is unique in that it focuses on all four phases of a PD program in extensive detail, and how those phases interact and inform each other. It incorporates a synthesis of literature on effective PD structured into a framework that can be systemically enacted. Using PrimeD provided a useful scaffold that centralized and synthesized the extant research on effective PD and provided a structure to effectively engage our partners and stakeholders. PrimeD helped us negotiate many challenges of managing a complex project while ensuring we considered the important components of PD, made intentional decisions, collaborated meaningfully with participants and other stakeholders throughout this journey, and reflected continuously on how to best meet the needs of the teachers and their students – all while keeping focus on our challenge space (as in Bryk, Gomez, & Grunow, 2010).

In essence, we came to realize PrimeD served as map that can be used to guide the design and implementation of a PD program and also to frame the evaluation of and the research on our PD program. As a map, PrimeD is complex, detailed, and expansive. We found that a single PD program, even a multi-year one such as ours, will not necessarily include every possible component shown in the map. Regardless, it was appropriate and important to consider all of the components so whatever was not included was done so intentionally. PrimeD helped us ensure all pieces of our PD program were aligned with one another so that, in sum, teachers received a well-designed, complete experience, and we were left knowing what worked well and what needed improvement (the evaluation component) as well as how and why certain components produced the associated outcomes (the research component).

Ultimately, teachers and their students receive a better product when PD is guided by a framework such as PrimeD. A PrimeD PD is not an isolated one-way conversation with teachers on how to teach their students, but rather, a non-hierarchical discussion among colleagues (i.e., teachers as partners rather than recipients) about the craft of teaching and the engagement of students in learning. PrimeD is built on the premise that effective long-term PD treats schooling as a shared responsibility among teachers, schools, and community stakeholders. A PrimeD PD goes beyond developing teacher knowledge or classroom practice to include opportunities for teacher leadership and collaboration. These collaborations engage teachers in actively contributing to the development of a common vision for teaching, evaluating the PD program and its activities, and assuming leadership roles in research in their classrooms.

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Enacting PrimeD was a drastic shift from traditional PD programs in this single case study. We learned daily how the framework itself could evolve and be modified to meet particular challenges. We encourage others to incorporate PrimeD as outlined here as a structure to guide the work of current and future PD programs. Using explicit PD models that incorporate research-based practices as outlined in PrimeD can lead to meaningful impact on the nature of PD and increase the probability of transforming teacher practice, increasing student learning, and contributing to the knowledge base on PD.

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