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A standards-based tool for middle school teachers to engage students in STEM fields

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A standards-based tool for middle school teachers to engage students in STEM fields (Research-to-Practice)

Strand: K-12 Engineering Resources: Best Practices in Curriculum Design

Middle school teachers play an instrumental role in promoting student interest in science and engineering fields. Studies have shown that engaging students early on can inspire students to pursue degrees in STEM fields for higher education. This work focussed on providing middle school teachers with resources to engage students using hands-on activities and demonstrations directly related to the state science standards. During the Fall 2012 term, a library of brief historical perspective, applications and activities was generated for 8th grade physical science standards. The demonstrations and activities were specifically selected to promote interest and engage students, while being easy-to-implement for the teachers. Beginning Spring 2013, video demonstrations were produced to assist content preparation. Concomitantly, the resources were designed to be accessible as a database on an iOS device such as iPhone, iPod Touch or an iPad. In particular, an app was designed to deliver the content with the ability to track progress. The app serves as a powerful reference and a guide for teachers to integrate science and engineering activities within their curriculum. Towards the end of June 2013 a workshop was organized for teachers to provide feedback on the project and test the beta version of the app. The project and the app were favorably received from workshop attendees, with several of the teachers requesting early access to the database for the 2013-2014 school year. In addition, crucial feedback and insight was collected from the focus group discussions following the app demonstration. It is expected as teachers begin to use the app and the content within, feedback and contributions from user community will further improve the quality and breadth of the content.

Introduction

Davis, *et al.* point out in their extensive review of literature on the Challenges New Science Teachers Face,[1] that there are appreciably high expectations when it comes to teaching science. Science teachers are expected to help students to develop "deep conceptual understanding … by engaging students in authentic scientific inquiry…" As a result, "Teachers must devise experiences that will help students construct understandings of natural phenomena…" Davis and co-workers document, often the instructors have limited background or time to prepare these experiences for their students, which in turn can adversely impact student interest.[1] Davis, *et al.* suggest a number of supportive strategies and programs to assist science teachers.[1] However, one particular form of assistance that can dramatically impact student engagement is the availability of hands-on activities and demonstrations that are easy-to-implement and are mapped to the local curriculum standards.

The New Jersey Core Curriculum Content Standards for science provide detailed learning goals for subjects including Physical Science, Life Science and Earth Systems Science for grades beginning with 2nd up to 12th Grade.[2] Based on preliminary surveys (discussed later in the paper) teachers indicate, though the guidance provided by the standards is specific, it is typical for them to identify and select the text necessary to prepare the content. In addition to making the content engaging for the students, it is necessary for teachers to incorporate hands-on experience to reinforce the concepts. Studies have demonstrated that hands-on student engagement with the topics being taught can positively influence their future interest in the subject.[3-5] Sources for hands-on activities, however are highly varied and more importantly are not always mapped to the Content Standards. Therefore, it is necessary for teachers to have access to easy-to-implement library of hands-on activities that are matched to the State Content Standards providing emphasis to the concepts and at the same time engaging the students.

While there are some very useful resources and notable efforts to align hands-on activities with the state standards, these often lack the accessibility to the teachers and at times are challenging to implement.[5-13] One of the strongest candidates is TeachEngineering.org, which began as an NSF-funded project in 2003 to develop a web-resource for teachers to incorporate hands-on activities to teach engineering.[14] TeachEngineering possess a wealth of resources (with over 1000 activities) that is continuously growing with support from engineering educators and teachers.[14] Yet our initial teacher survey indicates the teachers fail to incorporate such activities. At the same time, providing some historical context and applications of the concept in real world can further engage the students. Considering, most activities require moderate to extensive preparation for the activities to be included in the lesson plans. There is a need to develop a resource for teachers that is dynamic, flexible, well-aligned with state content standards, and provide simple in-class activities. Specifically, activities that can be typically prepared a day ahead using supplies that are readily available at a local grocery store. Furthermore, with the prevalence of mobile technologies among teachers, one can imagine a highly versatile resource that is specifically designed for the teacher's handheld device, such as an iPhone. Therefore, the overall goal of this project is to engage and inspire K-12 students towards STEM fields by providing teachers the necessary tools and resources. Specifically, to develop a library of simple activities and relevant content that is mapped to the NJ Core Curriculum Content Standards for Physical Science and delivered via a mobile app. This paper will detail the key steps towards developing a core content-mapped resource for middle school teachers, called CorePal. Also included is feedback from middle school teachers who were demonstrated early versions of the resource during a workshop, upon surveying their preparatory and instructional approach. The paper presents the latest build of the app and therefore the resource as it would be utilized by the teachers. We have received an overwhelmingly positive preliminary feedback from the teachers and we continue to add features as we prepare to launch CorePal in Summer 2014. Upon its launch, CorePal will exist as the only standards-based content tool on a mobile platform.

Background and Approach

Considering the breadth of the New Jersey Core Curriculum Content Standards, we strategically decided to narrow the focus at the initial stages of the project. This was done to ensure focus on building the critical framework of CorePal without being overwhelmed by the content development itself. As a result, only the 8th Grade Physical Science standards was selected. Figure 1 provides an example of the standards pages for a specific strand (Strand A). The standard includes a content statement and the corresponding progress indicator. Therefore, an instructor must develop the lecture to satisfy the learning objectives listed within the standards. Based on focus group discussions with middle school and high school teachers, it is typical for instructors to first identify a text or an online resource to develop the content for the lecture and design activities to emphasize the concept. It is often the case, that the activities the teachers identify require specialized equipment or supplies to demonstrate the concept. As a result, this project was particularly targeted to develop content and activities that require limited preparation time and use supplies that are readily available. Such a 'just-in-time assistance' is highly desirable for promoting integration of hands-on activities with lesson plans.[15-16]

It was also important to identify the type of content that was going to become part of CorePal. Rather than competing with instructional content that is available from textbooks, CorePal content focussed only on providing brief and easy-to-read reference to the standard. In other words, content that will supplement the lessons by providing some context to the topics and that teachers can expand on based on student interest. Specifically, CorePal is not intended to provide theoretical content but the real-world connections to the content standards as a way to motivate interest in the topics. Teachers can easily customize their examples based on student interest and background.

Content Area	**Science**		
Standard	**5.2 Physical Science:** All students will understand that physical science principles, including fundamental ideas about matter, energy, and motion, are powerful conceptual tools for making sense of phenomena in physical, living, and Earth systems science.		
Strand	**A. Properties of Matter:** All objects and substances in the natural world are composed of matter. Matter has two fundamental properties: matter takes up space, and matter has inertia.		
By the end of grade	**Content Statement**	**CPI#**	**Cumulative Progress Indicator (CPI)**
8	All matter is made of atoms. Matter made of only one type of atom is called an element.	5.2.8.A.1	Explain that all matter is made of atoms, and give examples of common elements.
8	All substances are composed of one or more of approximately 100 elements.	5.2.8.A.2	Analyze and explain the implications of the statement "all substances are composed of elements."
8	Properties of solids, liquids, and gases are explained by a model of matter as composed of tiny particles (atoms) in motion.	5.2.8.A.3	Use the kinetic molecular model to predict how solids, liquids, and gases would behave under various physical circumstances, such as heating or cooling.
8	The Periodic Table organizes the elements into families of elements with similar properties.	5.2.8.A.4	Predict the physical and chemical properties of elements based on their positions on the Periodic Table.
8	Elements are a class of substances composed of a single kind of atom. Compounds are substances that are chemically formed and have physical and chemical properties that differ from the reacting substances.	5.2.8.A.5	Identify unknown substances based on data regarding their physical and chemical properties.
8	Substances are classified according to their physical and chemical properties. Metals are a class of elements that exhibit physical properties, such as conductivity, and chemical properties, such as producing salts when combined with nonmetals.	5.2.8.A.6	Determine whether a substance is a metal or nonmetal through student-designed investigations.

Figure 1. A section of the NJ Core Curriculum Content Standards for Physical Science for 8th Grade. Includes a Content Statement, an index number for reference and the Cumulative Progress Indicator.[1]

The project efforts were divided into two major objectives specifically dealing with the 8th Grade Physical Science standards, as explained earlier. These objectives were, a) Content Generation which entailed identifying reference content and selecting activities for CorePal and b) Delivery Development, which involved development of a web-based content database designed to be delivered via an iPhone app. As a result the remainder of the paper provides details of the outcomes pertaining to these two objectives and presents feedback from the teacher workshop conducted in June 2013 during the preliminary demonstration of CorePal.

Content Generation

A simplified list of the Grade 8 Physical Standards for New Jersey is provided in Table 1. Short titles were generated for the database content. Content generation efforts therefore were divided based on the fifteen indices (CPIs) listed. For each CPI, a team of undergraduate engineering students developed content which was further divided into three aspects related to the topic. These were, History, Applications and Activities. The students were responsible for preparing brief and easily accessible reference for each concept. Sources varied but majority of the content was developed using web-based open-source content.

Table 1. A simplified list of 8^{th} Grade Core Curriculum Standards for Physical Sciences.

A. Properties of Matter
5.2.8.A.1 Matter
5.2.8.A.2 Substances are composed of elements
5.2.8.A.3 Solids, Liquids, and Gases
5.2.8.A.4 Periodic Table
5.2.8.A.5 Chemical Properties
5.2.8.A.6 Properties of Metals
5.2.8.A.7 Acid-Base Reactions

B. Changes in Matter
5.2.8.B.1 Conservation Law
5.2.8.B.2 Chemical Reactions

C. Forms of Energy
5.2.8.C.1 Solar Energy
5.2.8.C.2 Energy Transfer

D. Energy Transfer
5.2.8.D.1 Conservation of Energy
5.2.8.D.2 Energy Flow

E. Forces and Motion
5.2.8.E.1 Speed
5.2.8.E.2 Force Balance

The three content areas included History, Applications and Activities for each index referenced above. History, involved brief description of three to four individuals who contributed to the knowledge within a particular content area. This allows teachers to rapidly provide some context related to the development of the concept. Applications, provide four major applications of the concept index. Instructors can use applications to motivate the discussion of the concept and expose some real-world applications of the lesson - an important aspect of making science relevant.[4] Lastly and most importantly, each CPI includes three to four activities that demonstrate and elaborate the concept. Table 2 provides a sampling of the content that was generated for one of the standards related to Chemical Reactions. Note the length of the content was design to fit in a single view of a mobile device screen. The activities were selected particularly to provide teachers with easy to implement demonstrations or student activities to reinforce the concepts being taught. In addition, the team worked deliberately to identify activities that used materials that can be purchased typically at a local grocery shop and therefore required limited preparation from the teachers.

Table 2. Examples of a single historical content, a single application content and a list of activities for CPI: 5.2.8.B.2 related to Changes in Matter for Chemical Reactions. With Content Statement, "Compare and contrast the physical properties of reactants with products after a chemical reaction, such as those that occur during photosynthesis and cellular respiration."

History	Application	Activities
Antoine Lavoisier (1743-1794)	*Cement*	
		
Contributed greatly to the field of chemistry. He named both oxygen and hydrogen, proved that sulfur is an element and not a compound and identified combustion as a chemical reaction occurring with the oxygen in air. He also identified the reaction between oxygen and iron in steel as the cause for the formation of rust.	When combined with water, cement binds sand and rock together in concrete, and it provides much of the mixture's strength. Cement is a powdery substance composed of limestone, calcium silicates, gypsum, magnesium oxide, tricalcium aluminate, and tetracalcium alumino-ferrite. Once water is added to the powder, it triggers a series of chemical reactions that cause the cement to thicken, harden, and bond to the sand and stones.	*Lava Lamp* *Steel Wool Rust* *Fire Extinguisher* *Silly Putty*

Majority of the content was developed during the Fall 2012 term. During the Spring 2013 term a team of engineers began producing brief videos that demonstrate the activities. Considering this was a major undertaking to produce quality video content for almost 60 different activities, a single activity within each CPI was selected for demonstration purposes. The team made a conscious effort to produce consistent and content-focused videos for each activity selected. Figure 2 presents screenshots of two of the videos demonstrating two different activities. The activities videos were uploaded to YouTube and linked to the CorePal database. It is important to note that the videos serve a supplementary role to the activities for a quick demonstration of the procedure and the outcome. Therefore the video length was limited to around a minute for each demonstration. The descriptions on YouTube provide quick overviews of the activities, however detailed steps and discussion points are included within CorePal.

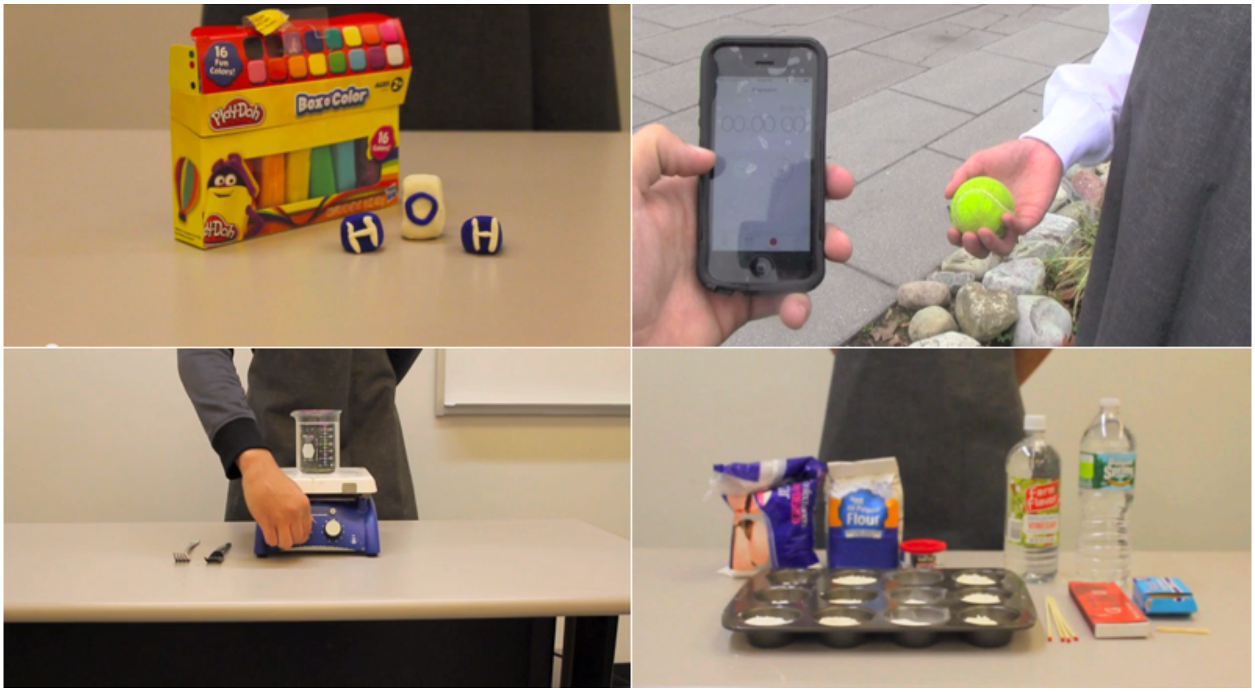

Figure 2. Screen captures of four activities or demonstration videos. The videos were embedded as links within CorePal and hosted on YouTube.com. Each video is approximately a minute in length.

Delivery Development

The content is organized by Physical Science Strands. As seen in Table 1 there are five strands, denoted by laters A through E, that are further divided into specific standards. This organization provided a good starting point for the database layout and navigation. Especially, considering teachers typically follow the standards in order to prepare their lessons. Each activity provides a static photo of the activity, a brief description, a materials list, step-by-step procedure, and discussion points for the teachers. Activities also include a brief video demonstrating the activity and the expected results. A representative image is also included with each application and the historical briefs.

To ensure the content is dynamic and scalable, a PHP database structure was designed. The database was hosted on a local server that the various portals (that is, mobile device apps and the desktop browsers) can access. The database is designed to easily add new content and edit existing content. In addition, the database also allows generation of specific list and storing user generated feedback in the future. The app versions of CorePal offer the ability to track one's progress through the curriculum standards and filter activities for rapid access, in addition to providing a better user experience. While the current version of CorePal content is static, it is designed as a more dynamic tool as development proceeds.

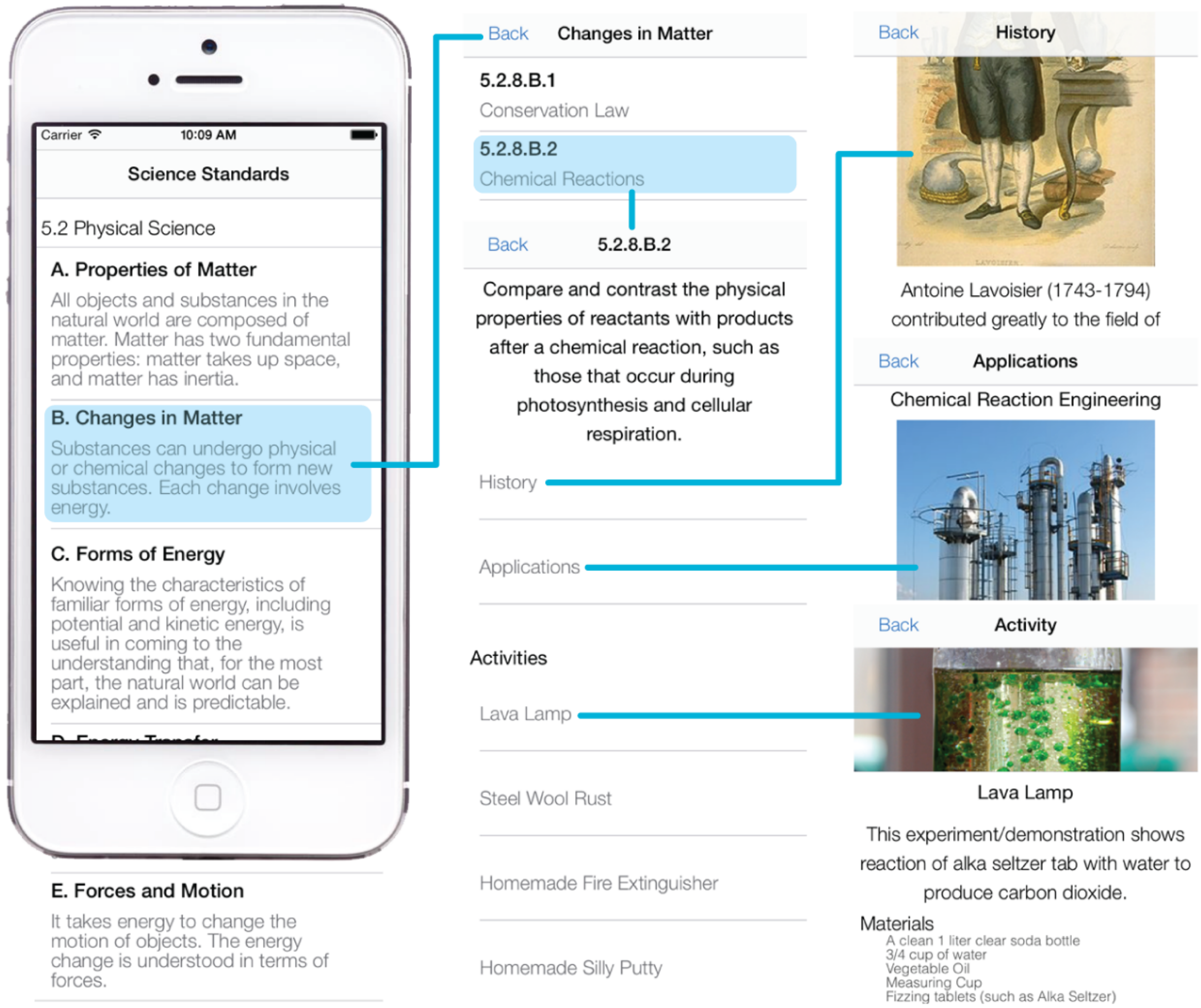

Figure 3. Content organization of CorePal for the iPhone app. Content is organized based on Physical Science standard strands and CPI descriptors. Demonstration videos are embedded within Activity view. Particular views are linked and highlighted in blue.

Figure 3 provides an image of the key features of the iPhone app in its current iteration. Launching the app reveals the key strands within the Physical Science branch, where the user can select the specific strand and proceed to the CPI content. Alternatively, the user can swipe left on the home screen to reveal the CPI list to directly jump to the specific CPI. Re-swiping to the left reveals all the included activities to quickly access a specific demonstration. Swiping right on the home screen provides information related to the project and the sponsors. The swiping gestures are not shown in Figure 3. The app is also designed as a checklist for teachers to track progress through the core curriculum standards. In addition to the content developed as part of this project, the app serves as a well-designed basic reference for specifics of the standards, as a few existing apps already offer.[17] Concurrently, an iPad version CorePal was developed. The benefit of the iPad version is that the content references are always accessible to the left for ease of navigation in addition to a larger viewing screen. The iPad version also features more visual elements of CorePal that are difficult to incorporate in the iPhone version.

STEM Teacher Workshop and Demonstration

On June 14, 2013, a STEM teacher workshop was held at Rowan University with 39 participants. The goal of this workshop was to present the overall project to teachers, show a preview of the app, and gain valuable feedback in order to improve CorePal development. A pre-workshop survey was conducted to assess the impact of state standards on teaching activities, the use of apps in the classroom, and the use of technology in the classroom. Over 89% of teachers indicated that their curriculum was at least in part driven by standards, with over two-thirds of teachers indicating that their curriculum is very strongly driven by state standards. Over 30% of workshop attendants use apps in the classroom to supplement instruction, and 100% use digital technology of some kind (laptop and desktop computers, SMART boards, web applications, etc). After reviewing the project goals and having hands-on time to experience a beta version of the CorePal app, teachers were given a post-workshop survey. All of the teachers indicated that the app would be useful in their instruction. When asked, "how do you think it will help?" a few representative responses were:

- I am excited to see how these apps are creating one place for teachers to look for such a variety of ideas.
- I like the breakdown linked to the standard. Easy to prep/outlines help.
- It will make lesson planning easier and more enjoyable.
- It will be a quick guide to finding activities and materials that match the standards.

When asked what the most useful features of the app were, typical responses were:

- The direct strands linked to all specific content (applications, history, activities). Everything seems very accessible.
- Application idea is a great idea. The kids always ask why.
- Video on demonstrations shows what actually should have happened.
- The organization it provides.

Of critical importance to app development, teachers were asked about potential improvements. Responses included:

- Work on this for lower grades. K-4 does not have to be science certified. And often not science comfortable. They probably need the help more than 8th grades.
- Correlation between Math, Language Arts and Social Students.
- Link with NGSS, Next generation science standards

- Try to incorporate math standards into the science lessons. For example, density used formulas to find volume that can be related directly to math.

Overall, the app was well received and the workshop has provided the team with valuable information to guide development.

Conclusion

As identified by the teacher feedback there is a strong need for a resource that maps to the content standards and provides hands-on activities to engage students in the STEM fields. More importantly activities that are easy to incorporate and require limited preparation. CorePal addresses this need by providing a highly versatile tool that aids teachers to provide better context and concept anchors for their students. Importantly, CorePal's layout is designed with the standards forming an organizational framework that the teachers already recognize. While CorePal has already demonstrated potential for its utility, the team is determined to add features that will prove critical to its success. Apart from improving the user experience for CorePal from the design standpoint, there is a major effort towards incorporating user feedback on the content. Specifically, the team is developing rating features so that teachers can rate individual CorePal activities. User ratings add a social element to the database and further enhance the user experience. In addition, to make the content more dynamic, we are integrating a method for users to submit content (that is, historical briefs, applications and especially activities). User-generated content will have the added benefit of being tested in a classroom setting by the teachers themselves. These two features are crucial for making CorePal a content-rich and dynamic resource for teachers. At the same time, we anticipate a strong user base will expand the database to include content beyond the 8th Grade Physical Science standard, as requested by teachers. At the same time, we are in the process of mapping the content to the Next Generation Science Standards (NGSS).[18] Mapping to NGSS, will greatly expand the applicability of CorePal. With these changes, CorePal has the potential to become an indispensable tool for teachers to inspire the next generation of students pursuing careers in the scientific and technical fields.

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