

**TEACHING MATHEMATICS AND PHYSICS BY  
DESIGNING PYROTECHNIC DISPLAYS**

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### **ABSTRACT**

This research deals with education in middle school mathematics. The topic is acknowledged to be very important, and hard to teach, often because of lack of student motivation. The approach here was to develop a teaching module that requires students to use mathematics as they design a simulated pyrotechnics display, using a student version of a software program suite, Show Director, that is actually used, worldwide, to design very large displays. A student version called PyroCreator Student was constructed. Experienced teachers designed and tested lesson plans using the program. After the initial research was successfully completed, future discussions include using the more advanced professional software, Visual Show Director, to teach mathematics and physics at the High School Level. These plans can be coordinated with US state and national teaching standards for mathematics. Student performance on relevant examinations can be compared to the performance of a control group that has received conventional instruction.

The intellectual merit of this project is that it provides a highly motivating vehicle for integrating mathematics into an engineering application that is coordinated with musical and visual arts evaluations.

The broader impact is that, if embraced by more schools, it could be available for use in schools throughout the nation. In order to ensure that this is an appropriate exercise, the program can be coordinated with nationwide standards of mathematics instruction.

## INTRODUCTION AND HISTORY

Mathematics is, obviously, a central topic in science, technology, and mathematics education (STEM). Middle school instruction is widely considered to be crucial in the development of interest in mathematics but, unfortunately, this is the place where student motivation often lags. Girls in particular have been found to lose interest in mathematics at the middle school level. Therefore there have been attempts to use interactive computer programs that will enhance student interest and can also be used to provide direct support in mathematics (Saylor, 2004), (2015 Geometer's Sketchpad). Non-traditional learners have been documented as becoming more engaged in group lessons and visually stimulating than non-traditional learning programs such as Jasper (VanHagen et al., 1992), (2014 Educause).

The original project was designed and tested in 2004 – 2005 in the Anacortes School District Middle School, WA, USA (AMS). The head teacher was also using this project as part of his Master's thesis "Virtual Fireworks Design in the Middle School Curriculum: Software Development for Technology and Content Integration" (Parson, 2005). He worked with Alberto Navarro, Infinity Visions, who provided the software and introduced the pilot program to the school. It was designed in the spirit much advocated by a widely cited National Academy of Science report, How People Learn (Bransford, Brown, & Cocking, 1999). We describe an activity that has been shown, in our preliminary work, to excite a great deal of student interest as they learn mathematics.

The program was designed to use simulated fireworks. This program for the creation of virtual fireworks shows was tested and introduced as part of the program at the Anacortes, Washington Middle School. Findings showed a heightened interest from students, especially middle school girls, compared to traditional software and math related programs. Special Education students also showed longer periods of interest than usual when working with the choices in this visually stimulating program. (Parsons 2005)

## APPROACH

The existing professional software uses complex math and problem solving to design professional pyromusical shows in 3D real time animation. The Student Version was a toned down version, allowing students to learn math techniques while designing and choreographing their own fireworks show to music. Students worked on designing fireworks choreography as the point of the exercise while we 'snuck' the mathematics in. The mathematics required included dealing with angles, measurement, height, distance, size, ratio, and perspective in order to solve problems in visual arts and choreography. We even provided exercises in business mathematics by providing students with a budget in "pyrodollars" that constrains their creative talents...just as a budget in real dollars constrains ours.

Students worked on a virtual fireworks display using the Eiffel Tower in Paris (Figure 1) as a backdrop. Enthusiasm was high and the students were noticeably engaged and attentive. Teachers accompanying the classes were asked to sit in and learn the program and to engage the students in conversation concerning the activity. The program remained on the computer following the classes for some time to allow the students to continue exploration of the program and create custom shows. Teachers were encouraged to engage the students in follow up activities. Poems and stories were written. Artistic representations of fireworks were created both digitally from the program and as paintings. Math discussions were held with regard to the geometry of the shows. The Music teacher expressed interest in doing a live presentation with the school band, choreographed by students to the virtual fireworks on a backdrop behind them.



**Figure 1** – Stage chosen for the exercise

## METHOD

The program was designed to teach skills based on the Washington State Educational Learning Standards “Essential Academic Learning Requirements” (EALR)

Weekly lesson plans were followed (Appendix A)

The following is a sample module.

### **Specific Math Skills and Concepts learned with the Basic Pyro Creator School Program**

#### ***Students will practice techniques involving:***

Measurement: (EALR 1.2, 5.2, 5.3) Measuring stage size and ratios (Proportion of stage size to height and size of each effect)

Calculating: (EALR 1.2, 5.2, 5.3) Calculating angles and correct positioning of effects for desired result

Diagramming (EALR 1.3, 5.2, 5.3) Planning and geometric sense

Planning a physical project (EALR 2.1, 2.3, 3.2, 5.2, 5.3) Preplanning, testing and correctly completing the desired program.

These map closely onto the following National Council of Teachers of Mathematics (NCTM) standards:

#### ***Measurement:***

- Understand both metric and customary systems of measurement.
- Understand, select, and use units of appropriate size and type to measure angles, perimeter, area, surface area, and volume.
- Use common benchmarks to select appropriate methods for estimating measurements
- Select and apply techniques and tools to accurately find length, area, volume, and angle measures to appropriate levels of precision.
- Solve problems involving scale factors, using ratio and proportion.
- Solve simple problems involving rated and derived measurements for such attributes as velocity and density.

*Geometry:*

- Describe sizes, positions, and orientations of shapes under informal transformations such as flips, turns, slides, and scaling.
- Examine the congruence's, similarity, and line or rotational symmetry of objects using transformations.
- Draw geometric objects with specified properties, such as side lengths or angle measures
- Use two-dimensional representations of three-dimensional objects to visualize and solve problems such as those involving surface area and volume.
- Use geometric models to represent and explain numerical and algebraic relationships
- Recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, science, and everyday life.

*Representation Standard:*

- Use representations to model and interpret physical, social, and mathematical phenomena.

*Connections Standard:*

- Understand how mathematical ideas interconnect and build on one another to produce a coherent whole.
- Recognize and apply mathematics in contexts outside of mathematics.

*Data Analysis and Probability Standard:*

- Find and interpret measures of center and spread, including mean and inter-quartile range
- Use proportionality and a basic understanding of probability to make and test conjectures about the results of experiments and simulations

***Applications of Mathematics***

*Problem Solving:*

- Build new mathematical knowledge through problem solving.
- Solve problems that arise in mathematics and in other contexts.
- Apply and adapt a variety of appropriate strategies to solve problems.

**Example of one of the exercises in the unit**

An Example of one of the exercises in the unit used in the pilot program is given immediately below, along with an illustration of one of the screens (Figure 2) seen by the students.

***Step 1: "Set Stage Size"***

*Concepts:*

Calculating Measurements, Distances, Perspectives, and Geometry

*Discussion Points:*

Stage size is calculated based on actual size of background, or students can design their own size.

Scale Size must take into consideration the scale size of the "Effects" that will be used on that stage. Example: If the Eiffel Tower is 300 meters, and you shoot an Effect on the Eiffel Tower that is 300 meters, it will take up the entire stage. If you shoot the same, 300 meter effect, from farther away, it will appear smaller on the screen.

Explain Perspective of the Scale "Zoom in" "Zoom out" means that when you change your perspective, you are showing what it looks like when you step back, or move up. The scale may be the same but the size of the effect will look different.

Figure out where your 'audience' is in order to choose your scale size.

Draw Diagram of Person looking at 300 meter object from different distances, show how they look smaller the further away it is.



**Figure 2 – Measurements and scales**

***Step 2: “Set Firing Positions”***

*Concepts:*

Measurement - Use Scale measure to set positions at different distances in relation to each other.

Example: USING SCALE RULER:

Set Positions 1 and 5 equidistant from position 3.

Set Position 2 equidistant from 1 and 3.

Set Position 4 between 3 and 5.

***Step 3: “Placing Effects” Contact between Measuring and Geometry.***

*Effects of Measurement, Symmetry, Patterns:*

Each Effect has a Diameter range of 75 mm-300 mm that can be chosen. Many different geometrical shapes and patterns of effects can be chosen (Figure 3).

Example: Choose different Diameters of the Effects based on the effect you need to produce. Is 75mm too large an effect or too small for that position?

Symmetry Example: Find Symmetrical patterns for each position 1 through 5.

Geometry Example: Show how the size of the spread of the effects affects the duration of the effect

Size: Changing the size of the Effect will also change its duration in Time

Geometry and Measurement: Choose different angles for each Effect from a scale of 60-120 at 15 degree increments.



**Figure 3 – Measuring and Geometry**

Explain this Concept in more detail using a diagram of angles and half circle.

Example: Shoot your effects in a half circle from position 1 to 5 calculating 15 degree increments, so that you display a semi circle of effects.

Example: Changing the angle will also change the ‘shape’ of the symmetry, so you may have to adjust the size” caliber”.

Example: Shoot the 5 positions so that they are all parallel. Shoot from different angles, by changing the size of the effects.

Symmetry and Sequencing: Explain the difference between positioning effects straight up, having them move in sequence across the sky, or by angles.

## RESULTS

The acceptance by both students and teachers was very high. Anacortes Middle School (AMS) continued to use the PyroCreator program in the 2005-6 school year. A Likert Scale instrument was used for evaluation of feedback from teachers and students with regard to the integrated PyroCreator units conducted at AMS (Likert Scale, Appendix A, B). These evaluations showed high levels satisfaction for both student enthusiasm and participation and for teacher perception of student accomplishment and learning. Math teachers as well as Art teacher and Band teacher expressed interest in including it in their curriculum as a cross-disciplinary project.

Students were quoted in the district newsletter (ASD April 2004) with remarks from 7<sup>th</sup> grade girls such as “It’s really cool. We got to do our own designs and displays,” and “It was fun. We added music to it so the fireworks changed to the different beat.” We can rest assured that gaining student attention is not going to be a problem.

In addition, the instructor who was writing his own master’s thesis on this project interviewed the relevant teachers (Parson, 2005). They said that in the pilot program the girls were particularly engaged in the program, which was not usual for computer-based units in the school. There was discussion that perhaps the artistic elements and musical elements of the program were appealing to many of the girls. The Special Education teacher was also very enthusiastic with the fact that his

students also remained engaged in the task for long periods of time, and even came in during tutorial to continue working with the program.

It was hoped that the program would find its way into educational curriculums throughout the region with further hopes of someday having a well-orchestrated curriculum available for adaptation by middle schools across the nation. In that effort inquiries were made and reflections solicited from various educational leaders from throughout the Northwestern region of the US. Response was very positive, as can be exemplified by the comments received during the program, for example from Earl Hunt, Ph.D. Professor of Psychology University of Washington. He said, "Pyrotechnic shows have been fun, worldwide, since at least the 1700s. PyroCreator is an elegant programming technique for producing a virtual fireworks show. In order to do this the user has to combine mathematical reasoning (geometry, measurement) with a sense of timing and an eye to combining visual and auditory signals into an artistic multimedia presentation. The addition of a budget in 'pyrodollars' presents the budding artist with a real-world constraint. The creators of the program have shown that the mathematical tasks in PyroCreator can be aligned with state and national standards for teaching middle school mathematics. Teachers can use PyroCreator to pose mathematics problems that students will rush to do in their free time."

## DISCUSSION

### Goals for future development of the program

This study was done between 2004 -2006. The results were very positive, yet due to lack of educational funding the program unfortunately were not continued. Since then both software and technology have greatly advanced. Students need to learn new skill sets to keep up with the future changing work force (Will We Be Smart Enough? Hunt, 1995). Finding new ways to teach these skills helps students from a variety of backgrounds and learning styles (Human Intelligence, Hunt, 2012). Teaching these skills through exciting and engaging programs such as designing a virtual fireworks display is a relevant program to continue to develop.

Ten years have passed since this study and now in 2016-2107 research has recommenced. As this paper is being written, research is in process at the Universidad Tecnologica del Valle del Mezquital, Mexico (UTVM). Current discussions and experiments are in place with professors and students from UTVM. Professors in mathematics and physics are currently working with students to create lesson plans using the advanced version of Visual Show Director Software, FX Generator (Bravo, Flores, Cano).

In Washington State, Dr. James Minstrell, Facet Innovations (facetinnovations.com) is also advising with lesson plans and educational uses of the software. Dr. Minstrell is a leader in research and development projects related to assessment, professional development and teaching of mathematics, physics and integrated science and mathematics at the high school level.

With their input, the idea to produce a more advanced teaching program is being researched for High School Math and Physics based on the current US Learning Standards (CORE) for Middle School and High School. Following are some examples of the work in progress and sample teaching units both in the US and in Mexico.

### Mexico

Topics that have been identified by UTVM that can be integrated into their curriculum using Visual Show Director Scripting Software:

Interpretation of vectors and spaces

Vector algebra vector algebra laws

Conception of cylindrical and spherical coordinates

Speed and acceleration

Circular movement

Particle movement



Calculation of angular speed  
 Newton laws of motion, movement, work, energy and momentum.  
 Differential equations (obtained from equations that produce velocity, acceleration, and more.)  
 Statics, equilibrium of a particle acceleration and gravity (gravitational system), projectiles mass analysis and static systems  
 Spherical and Cartesian coordinates.

Following is an example of lesson plans that are currently being developed at UTM for Mathematics and Physics using Visual Show Director scripting software.

**Lesson on Vectors and Coordinate Systems**

Using “FX Generator” and “Particle Generator” Fireworks Simulation Software

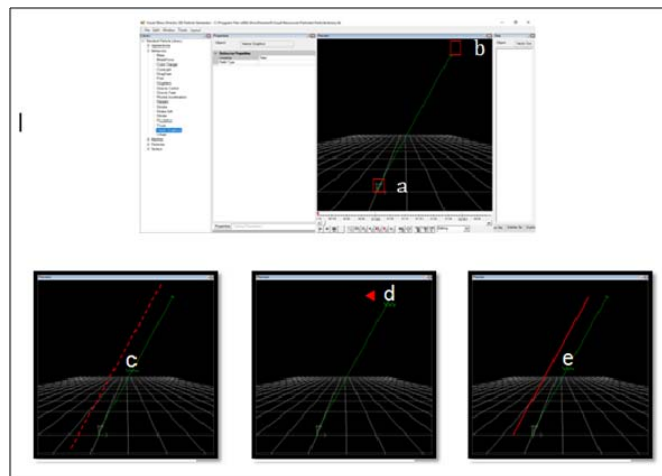
Vector Definitions: A quantity that has magnitude and direction, commonly represented by a Line Segment, counted from a point in space, whose length represents the magnitude, and whose orientation in space represents the direction. Vectors are geometric representations of magnitude and direction and can be expressed as arrows in two or three dimensions.

**Graphic Representation**

Graphically, a vector is represented as an arrow on a coordinate axis. A vector complies with the following properties:

- a) Magnitude: The distance between the origin and end point corresponds to the magnitude. The magnitude is a scalar quantity, a scalar being defined as a quantity, which may be completely specified by a number.
- b) Direction: The tip of the arrow determines its direction
- c) Origin or ‘Tail’: Point from which the arrow begins.
- d) End or ‘Head’: Point where the arrow ends.

After defining the concept of a vector and describing its properties, we can consider Fireworks as Vectors because they have the same properties (Figures 4, 5 and 6).



**Figure 4 – Vectors graphical representation**

**Create Vectors Lesson Practice Activity.**

- 1) Define the concept of Vector:
- 2) List the properties that make a Vector:
- 3) In the following images, Draw/Recreate these Vectors:

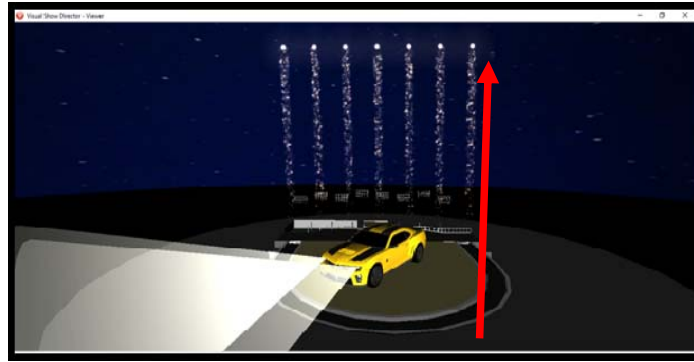


Figure 5 – Viewer

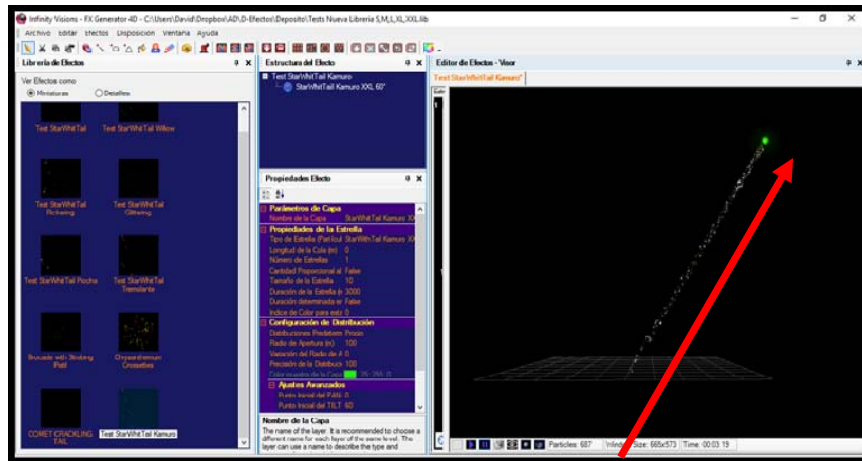


Figure 6 – FX Generator

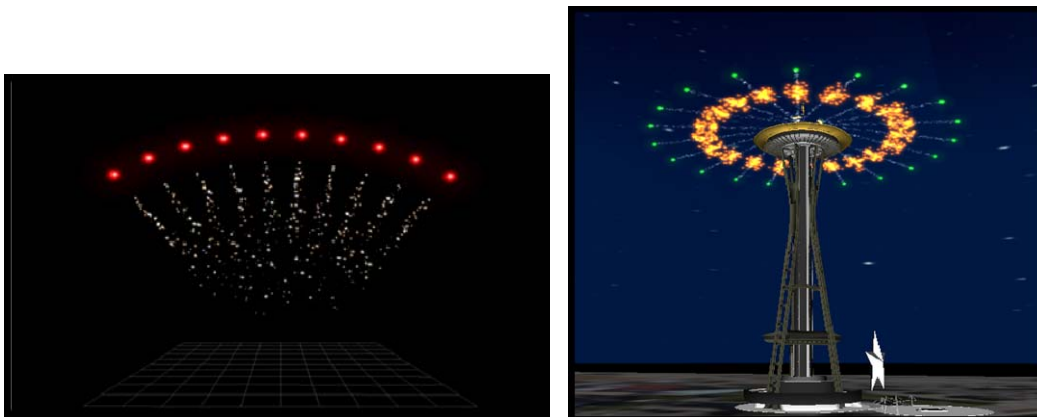


Figure 7 – Viewer with 3D representation of effect

## CONCLUSION

These are only a few examples of how lessons can be created around visualization software for fireworks displays. It is our hope that these ideas and units will be further developed and integrated into school programs by interested teachers who would like to take on this interesting and fascinating task. Comparing our study of 2004-2006 with the possibilities available today is very exciting. Technology today is more widespread, with more options, and students and teachers are more tech savvy. Students today more than ever are very focused on screen time and technology so that using a Pyrotechnics based

educational software program can be readily introduced as a learning device. Along with the enticement and excitement of learning about the fascinating field of Pyrotechnics, students can be engaged, motivated and entertained while learning math, science, art and technology.

### ACKNOWLEDGEMENTS

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Gianluca Alberico, Infinity Visions Inc. 2008  
David Cano, Universidad Tecnologica Del Valle Del Mezquital  
Eng.Ramon Bravo, Universidad Tecnologica Del Valle Del Mezquital  
Eng.Jose Eduardo Flores Ortega, Universidad Tecnologica Del Valle Del Mezquital

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*National Council of Teachers of Mathematics* (<http://www.nctm.org/>)  
*Facet Innovations* ( [www.facetinnovations.com](http://www.facetinnovations.com))

**APPENDIX A:**

Lesson Plans for 1 week introductory unit using PyroCreator & PyroPlayer  
 Advance copy to each cooperating teacher

Location: AMS PC Lab  
 Class time: 47 minutes/ class / day

	<b>Activity</b>	<b>Responsible</b>	<b>Resources and comments</b>	<b>Time</b>
<b>Monday</b>	Introduction to PyroCreator and Mr. Navarro	C. Parson	Projector & web page on AMS site with links to published articles and movies of completed shows & images	5min.
	Demo of program basics	A. Navarro		15min.
	Explanation of Image software and format..... why .JPEG	C. Parson	Laptop, Projector, sequence plan,	9min.
	Assisted Student exploration & work time	A. Navarro, C. Parson and all cooperating teachers	Mac. Fireworks / all computers sample images, camera  Student computers with preloaded software & projector/ laptop for ongoing examples and hints	18min.
<b>Tuesday</b>	Geometers SketchPad and key geometry concepts for use with PyroCreator	C. Parson & cooperating Math Teacher	Geo-Sk Pad / all computers and PowerPoint presentation on angles and plane	12min.
	PyroCreator wizard and file set up	A. Navarro	Laptop, projector and programs	10 min.
	Assisted Student work time with tips	A. Navarro, and all cooperating teachers	All computers and network in function with PyC, PyPl, and support programs	25 min.
<b>Wednesday</b>	Welcome back, file saving location and audio tips / multi-media room	C. Parson	Audio recording program set / use with laptop and projector	5 min.
	3 demensions and solid geometry with movable views in PyCr	All / math teacher led  All	Demo of rotation by Navarro with projector &laptop	5 min
	Assisted Student work time with tips	C. Parson	All computers and network in function with PyC, PyPl, and support programs	37min. ongoing

	Audio Room supervision		M.M. Room	
<b>Thursday</b>	Assisted Student work time with tips	All	All computers and network in function with PyC, PyPI, and support programs	47min.
	Audio Room supervision	C. Parson	M.M. Room	ongoing
<b>Friday</b>	Assisted Student work time with tips	All	All computers and network in function with PyC, PyPI, and support programs	25min.
	Selected student program review / Class	All	Projector, student login cap. and laptop with all programs	17min.

In class time to be supplemented by before and after school open lab for student use.  
Hints and tips provided by A. Navarro to be given on ongoing/ override basis

Please Initial / Approval:

**APPENDIX B:**

Technology Integration Inclusion (Teachers Only after completion of unit)

<p><i>Please place a check mark in the appropriate box to the right of each statement below in order to indicate your level of agreement with the statement.</i></p>	<p>Strongly Agree</p>	<p>Agree</p>	<p>Not Sure</p>	<p>Disagree</p>	<p>Strongly Disagree</p>
Middle school students enjoy using the PyroCreator program.					
Middle school students learn new skills using the PyroCreator program					
I have frequently used team teaching prior to this unit.					
I always thought that teaching music and math together made sense.					
I have used Geometer's sketch pad in the past.					
I have never combined the teaching of music and concepts from my content area.					
I have used software specifically designed for technology integration in the past.					
I was already familiar with software for recording and editing music.					
I have frequently incorporated several different content areas in my past lesson plans.					
I expected that the PyroCreator program would be very useful to my class.					
In the past, I have used technology frequently in my content area classes.					
I am a good computer user.					
Increased technology integration could be valuable to my students.					
I knew how to edit a .JPEG image before exposure to this unit.					
Geometer's SketchPad helps students to learn Geometry concepts.					
By using more music I can create higher interest in content area concepts.					
I feel that the importance of technology is over emphasized for today's students.					
I now believe that the PyroCreator program would be very useful to					

my class.					
After this unit I am more familiar with software for recording and editing music.					
I personally gained technology skills by working with the students on this unit.					
I am a better computer user after having learned skills associated with PyroCreator.					
I plan to use more technology to reinforce my content lessons.					
I can edit a .JPEG image					
Students enjoyed working with this unit.					
I will team teaching more frequently in the future.					
Students can learn important math skills while working with music.					
I will use Geometer's Sketchpad in the future.					
I will use more technology integration in the future.					
I feel more confident now in coordinating an integrated unit using technology.					
I will combine the teaching of music and concepts from my content area.					
I will use software specifically designed for technology integration in the future.					
I will more frequently incorporate several different content areas in my past lessons.					

<b>Tally completed manually using pencil</b>	<b>Degree of Shift</b>								
<b>Questions where significant shift is shown.</b>	Plus 4	Plus 3	Plus 2	Plus 1	0	-1	-2	-3	-4
<b>Questions where willingness to incorporate PyroCreator and Technology integration is shown.</b>	Plus 4	Plus 3	Plus 2	Plus 1	0	-1	-2	-3	-4
<b>Questions where reluctance to incorporate PyroCreator and Technology integration is shown.</b>	Plus 4	Plus 3	Plus 2	Plus 1	0	-1	-2	-3	-4



## APPENDIX C:

### US Middle School Math Sample Lesson in Math and Physics using Visual Show Director Software.

Based on Common Core Standards

Dr. Jim Minstrell, Facet Innovations

Introductory Lesson. Start your lesson with a Bang! Show the end result, e.g., a fantastic 30 to 60 sec. virtual fireworks show. Now that you have captured your student's attention, you can begin with the lessons. Demonstrate some ideas from math and physics that can be generated and/or applied in the creation of a fireworks display

**Table 2** - Show the math functions and physics of independence of horizontal and vertical motion for projectiles in creation of an element of the fireworks.

**Table 3** - Show the spatial geometry of orienting the horizontal and vertical components of the launch of an element into the space of the display.

**Table 4** - Show the same for a second (repetition) element to show a step in creating a pattern within the display) through time.

Applying MS and HS math, physics, and technology to engineer a fireworks display  
2017 CORE modules identified to be integrated with Visual Show Director Scripting Software.  
([www.corestandards.org/Math](http://www.corestandards.org/Math))

Mathematics Standards (Appendix D: Sample lesson plan)

Grade 7 (Ration and Proportion, Relationships, Equations, Geometry)

Grade 8 (Equations, Functions, Geometry)

HS (Functions, Modeling, Geometry)

#### Sample Lesson: Planning the path of one firework

Direction of the launch in spherical space

Direction horizontally in degrees from an arbitrary zero direction

Direction vertically in degrees from horizontal

Location of the projectile in a vertical plane:

Function for horizontal motion  $X_{hor} = V_{hor\text{initial}} \times T + X_{\text{initial}}$

Function for vertical motion  $Y_{vert} = (1/2)9.8 \times T^2 + V_{\text{initial}} \times T + Y_{\text{initial}}$

Independence of horizontal and vertical motion from an experiment mapping (1 s intervals) the horizontal and the vertical distance from the point of a projectile launched horizontally with an initial  $V_{\text{horizontal}}$  and then only under the influence of earth's gravity.

Launch velocity,  $V$ , as a vector

Resolution of vectors into horizontal and vertical components  $V = V_{\text{vert}} + V_{\text{hor}}$  (as vectors)

**APPENDIX D:**

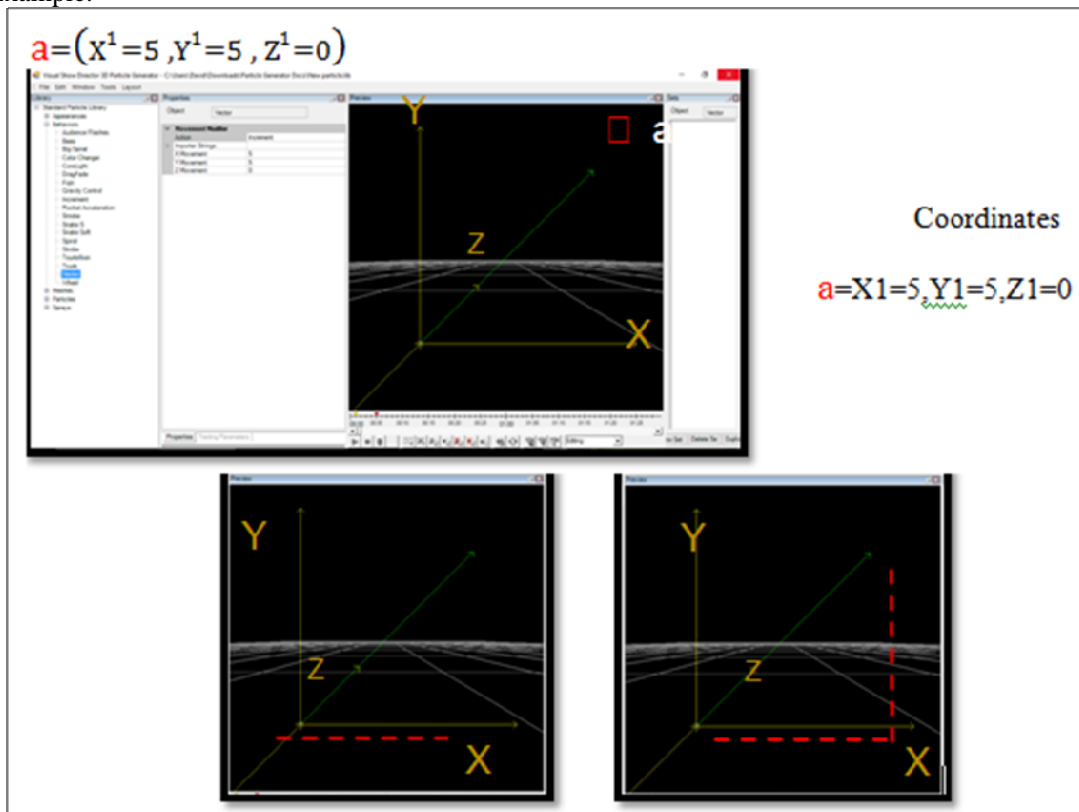
**High School and Upper Level Math Sample Lesson on Coordinate Systems, using ‘Particle Generator’ and ‘FX Generator’ Software  
Universidad Tecnologica del Valle del Mezquital, Mexico. David Cano.**

A coordinate system is a set of values and points that allow you to define the position of any point of space. The study of vectors is facilitated if we place them in a Cartesian, polar or spherical coordinate system for greater precision, in order to represent the vectors from an algebraic form into a geometric form.

Cartesian coordinate system (x, y, z)

A Cartesian coordinate system is defined by two axes (y, x) in a two-dimensional system and a three-axes system (x, y, z) in a three dimensional system, which intersect at the origin.

Example:



**Figure 8 – Cartesian coordinate system. Particle Generator**

This means that 5 units are moved first on the X axis, in order to then move 5 Units in the Y axis.

In the software application "Particle Generator", managing vectors in Cartesian planes is essential for creating the behaviors (Modifying movement) which are then applied in software application "FX Generator" to Stars in order to create different effects. For this reason, the "Particle Generator" in combination with "FX Generator" are excellent software tools for learning the Cartesian coordinate system.

**Coordinate System Lesson, Practice Activity 1:**

In "Particle Generator" draw the following coordinates in order to create a new behavior. Then in "FX Generator" apply this behavior to a comet and observe the effect created.

**Coordinates**

a = Origin

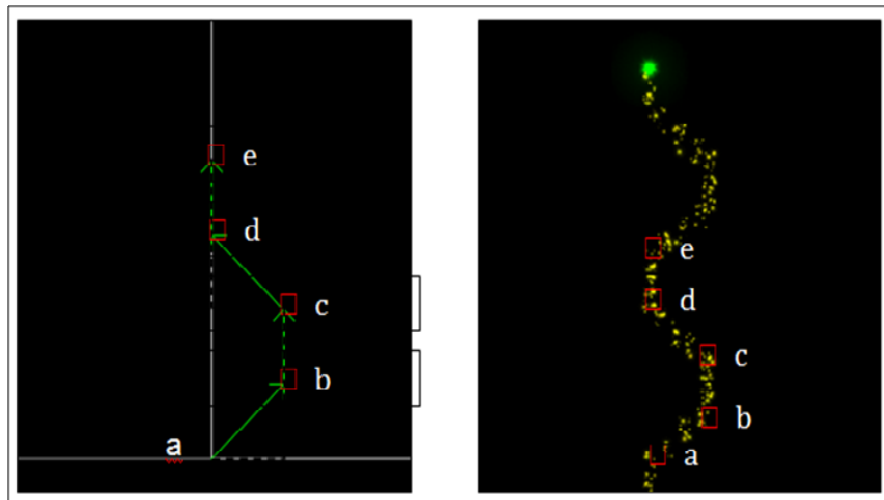
b = X2 = 1, Y2 = 1, Z2 = 0

c = X3 = 0, Y3 = 1, Z3 = 0

d = X4 = 1, Y4 = 1, Z4 = 0

e = X5 = 0, Y5 = 1, Z5 = 0

Result:



**Figure 9** – Behavior vectors/Particle Generator

