Interactive Visualization of our Solar System Using a Web Browser

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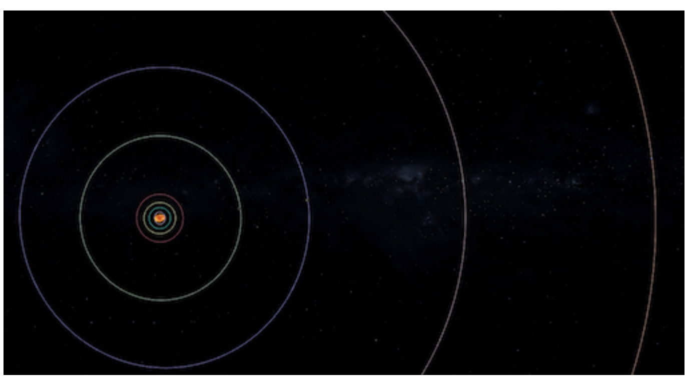

Fig. 1. Displaying our Solar System

***Abstract*—As the world wide web continues to expand, its use-cases grow. Educators and students alike can leverage its power and scale. This project aims to cohesively visualize the planets of our Solar System and demonstrate all the planets relative to the Sun and the Earth, using a web app implementation. The orbits of the planets are elliptical and defined by the plane of the Earth's orbit. This project envisions to calculate the rotational and revolutionary aspects in order to determine the speeds of the planets. Our Solar System consists of the Sun and the planets - Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and dwarf planets like Pluto. There are about 150 moons in the orbit of the planets in our Solar System. This project sources the open-source planetary data from NASA. This project utilizes many open-source web frameworks, such as JavaScript, WebGL, and SAGE2, to implement the dynamic, interactive visualization.**

***Index Terms*—javascript, webapp, education, accessibility, web services, web sites, open educational resources, open source, astronomy, outer space, planets, web development**

I. Introduction

Since the beginning of Internet's existence [13], it has had unprecedented growth. Originally created as a research project in the 1960s [15], it has transformed the landscape of modern information as we know it. Billions of humans are connected to each other with just a push of a few buttons instantaneously. At the current pace, over 2.5 quintillion bytes are created by us every day [14], and will continue to grow. The Internet has evolved to be an open space for billions of people to communicate, create material, and educate

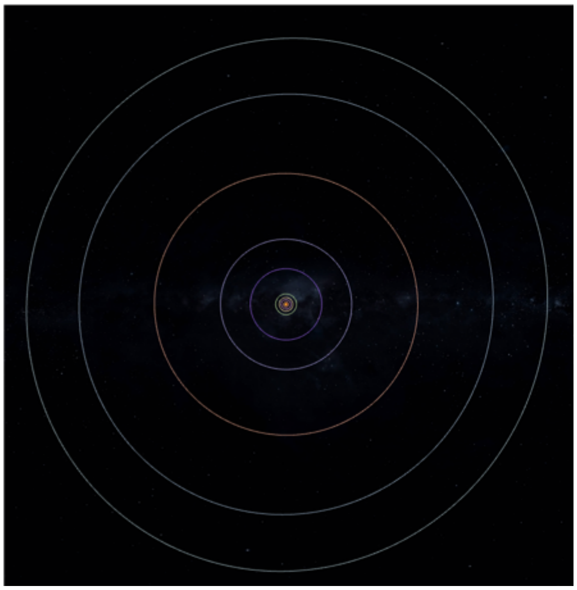

Fig. 2. Displaying our Solar System

each other. The traditional education system without the Internet has been limited to location, resources, physical teaching materials, and money. Leveraging the scale of the Internet has been used to connect educators with vast, accurate, free learning material and the touch of a button. Astronomy and space science have a strong appeal to children in K-12 classes, adults, and space enthusiasts alike. It is a dynamic and exciting science, which is deeply rooted in their everyday life and in the surrounding culture. Teaching astronomy at the primary and secondary school levels is can be challenging for science teachers, because it contains complex subjects in physics, requires an understanding of three-dimensional geometry and dynamics, and demands advanced cognitive and reasoning capabilities on the students' side. To understand the basic astronomical phenomena such as day and night and the occurrence of seasons, eclipses, phases of the moon, tides, years, leap years, and the motion of the planets, they must have the capability of visualizing events and objects; as these may appear from different perspectives simultaneously. Astronomy teaching is considered difficult also because of the large amount of facts and details it contains, and because some of the concepts seem abstract and out of reach. Teachers are often faced with the dilemma of what topics from the large curriculum to cover in the limited time frame that is usually allocated. Children can have initial conceptions and ideas about celestial objects and phenomena, which are often reminiscent of ancient philosophical ideas, like Aristotelian geocentric views of the sun and planets.

Piaget noted many such conceptions in his early studies of child development, and showed that children evoke their own cosmological explanations even at very young ages. As they grow up, their early ideas are probably influenced by fictitious information presented in everyday culture and mass media, such as science fiction movies, TV series, social media, and the Internet.

The early cosmological ideas were deeply rooted in non-scientific beliefs, and were often inconsistent with the accepted scientific view. Some of these alternative frameworks continue well into adulthood and are even found in university students. DeLaughter et al. present a variety of misconceptions found among students in an introductory earth science course and cite the famous Shapiro et al. (1988) video that showed Harvard graduates failing in explaining the cause of seasons on Earth. The common misconceptions students have in astronomy may come from factual misinformation, mythical concepts and language imprecision, misinterpreting sensory information, and incomplete understanding of scientific processes (Comins, 1993). Without a contextual framework within which to compare astronomical objects (that is, specific tasks or everyday experiences), students have difficulty in mentally filing the facts associated with them. They also have difficulties in creating the "big picture" from its various components (Bennet, 1999). The objective of this project is to cohesively visualize the planets of the Solar System, with respect to the Sun and the Earth, using a webapp interface. Students can gain a basic understanding of astronomy using the simple webapp interface. Typically, using a webapp implementation ensures most users will be able to use it, without downloading additional software.

II. The State of Scientific Data Visualization

The goal of data visualization is to allow users to digest otherwise indigestible data. In the current modern era, there is a vast amount of information to be consumed and analyzed. Scientific visualization allows for the investigation of large (and small) amounts of data. Researchers have used scientific visualization to answer questions, and form new ones. In its modern, digital version, scientific visualization links science, technology, computer science, and applied visual arts in the designing of systems that can translate huge amounts of quantitative data into digital graphic images. However, even a rather simple and unique form of scientific visualization in planetary sciences,

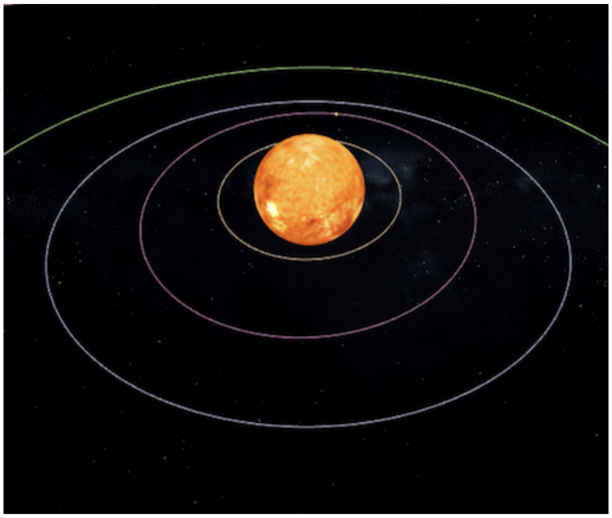

Fig. 3. The Sun

such as the one introduced by Miller and Hartman (1993), can be a powerful tool for teaching. They drew pictures, views, and landscapes of planets, moons, and asteroids, based on the scientific data transmitted by the Voyager and Pioneer spacecraft and those obtained by Earth-based telescopes. They provided vivid and spectacular renderings of the clouds of Jupiter and the rings of Saturn, as well as of the volcanoes of Io and the craters of Miranda, the moon of Uranus. These images enabled one to tour and study the surfaces and atmospheres of different planetary objects in the solar system, with no other means but a still picture. Modern computers with powerful graphics enable scientists to use more accurate variations of color and shading to represent numerical data, that describes different aspects of natural phenomena and processes. These representations can portray complex concepts and phenomena in their entirety. They can also consist of a series of images depicting changes over time. In relation to astronomy teaching, scientific visualization can easily become a powerful strategy to overcome the described hurdles. Images from satellites and spacecraft, as well as from the Hubble Space Telescope, become a source to new scientific information. Classroom materials, lesson plans, and complete courses have already been developed by NASA. The introduction of virtual reality (VR) technologies to desktop computers has greatly increased the ability to simulate and present complex three-dimensional objects and phenomena to the average computer user (Mohler, 2000). This trend coincides well with the notion promoted by Bliss and Ogborn (1989), who stated that computerized simulations act as an exploratory tool and promote the user's understanding of complex dynamic processes. Barab et al. (2001) have presented a virtual solar system as a tool for teaching astronomy. Lately, Yair et al. (2001) have described the application of scientific visualization technologies to astronomy teaching. They developed a three dimensional model of the solar system, which includes the sun, planets, moons, asteroids, and comets. In this model, all these objects revolve and rotate in their orbits against the constant background of the Milky Way, the stars, and the constellations. High-resolution NASA photographs were used and the planetary orbital data were calibrated with great accuracy. The user enters a virtual model of the physical world, where the computer mouse functions as a spaceship of sorts. This permits a journey in the virtual representation of outer space, enabling students to zoom in or out as they wish, easily changing their viewpoint and perspective. Such a learning environment offers an exciting learning experience and facilitates the construction of a scientific concept of the solar system (heliocentric vs. geocentric). A previous at Tel Aviv University (Gazit and Chen, 2000) shows that students require guidance and assistance in their interaction with the astronomy VR program, and that they have difficulty in constructing their knowledge without mentoring and mediation by an instructor or a teacher.

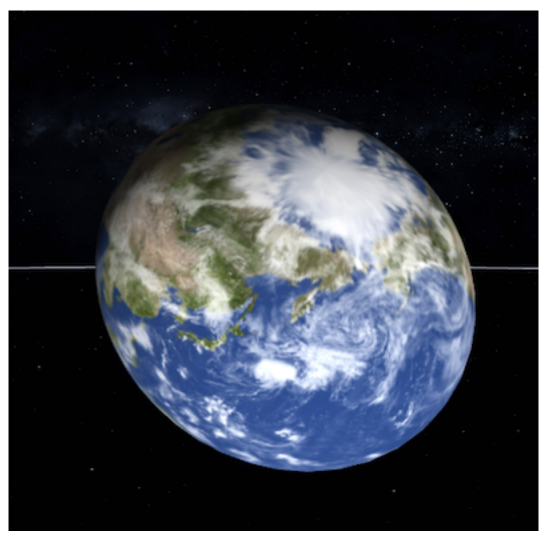

Fig. 4. Earth

III. Philosophy and Education

Galileo and Einstein were regular conductors of thought experiments, an intellectual exercise, discussing questions of gravity and of relativity theory, respectively.

Thought experiments can be used in educational settings as well, providing a powerful stimulus for children studying science. Children and early students can learn how to be curious, and form research questions at an early start. Schur introduced the Thinking Journey concept to astronomy education for children. The Thinking Journey uses images of Earth and the Moon, as well as of spaceships and astronauts. It encourages students to be directed and coached in a gradual, structured manner, and to investigate and discover various subjects in basic astronomy. The approach is based on the works of Feuerstein et al. (1988) and Feuerstein (1998), that focused on the relations between the way children observe natural phenomena and their abilities to understand them. These works describe the connections between thinking processes and the ability to observe a phenomenon and its changes. For Feuerstein, learning science includes observing the organization and regularity of natural phenomena, which is a necessary prerequisite for understanding the relevant scientific facts and content. After learning these scientific concepts, the way is paved for the child to observe the phenomenon in a new manner and to understand it.

In his book, Schur (1998) devised a cyclic learning process that is composed of six stages.

The guiding principle of this process assumes that for learning to take place children must undergo a conceptual change, and that they must be performing tasks involving the subject matter, under the supervision and mediation of their teacher. For studying astronomy, children are initially asked to observe a phenomenon (either directly in the sky, or in an image from space). They are then guided (by targeted questions referring to the image) to define and collect the results of their observations. Then, they analyze the data, explain it, and look for interconnections between different items. At this stage, the teacher (tutor, instructor) supplies additional information, as well as guidance and counseling. The children then draw conclusions, generalize the observation, and look for rules (or natural laws). The last stage is an introspection of the previous stages, to create awareness and as a preparation for a repetition of the process to the next assignment (=observation). This is a dynamic learning process where students are active participants in the acquisition of knowledge, rather than passive recipients of information. The place of the learner is important and explicit throughout the learning process. The learner is not the outside observer who watches the phenomenon. The learner is a part of the context. Since many students have difficulties with mathematical and verbal skills, ways must be found to enable them to interact with the physical environment while circumventing the mathematical and verbal obstacles. Using pictures of the Earth, the Moon, and outer space enables students to interact with a congenial modality. Students find the pictorial modality familiar: they are accustomed to it in their everyday interaction with television, movies, and computers. Perrig and Kintsch (1985) observe that the pictorial modality is easier for students to remember and to understand than the verbal modality.

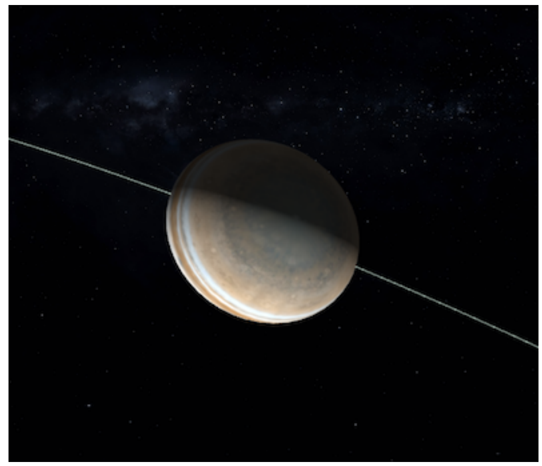

Fig. 5. Jupiter

IV. Connecting Philosophy and Education

An exploratory effort to combine the Thinking Journey method with a multimedia-based astronomy program has been carried out at the Center for Educational Technology in Tel Aviv. The authors have used the "Touch the Sky, Touch the Universe" astronomy, which was widely used in schools throughout Israel, to develop a special training program for K-12 science teachers. This program utilized the mutual strengths of both components and implemented the cyclic learning process to dynamic animations, MPEG movies, and still images embedded in the various items within the software. The positive outcome of these teachers' courses paved the way to applying the new concept to an astronomy program for high-school students who do not major in science. Taking advantage of the fact that the power of visualization technologies has increased significantly in the last couple of years, we created a three-dimensional visualization that focuses on viewing the solar system. We chose to focus on the planets in our Solar System because it is one of the most exciting scientific targets of research and the object of dedicated space missions. The planets were rendered using open-source planetary data from NASA.

Using a mouse, the user is allowed to zoom in and out, pan, rotate, and tilt the image according to their chosen viewpoint. Figure 2 shows our Solar System, zoomed out. This image reflects the capabilities of the open-source libraries we used, and many important details can be deduced by simply observing the emerging planetary landscapes. The user can zoom in further to observe and explore other planets and celestial bodies (Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto). This allows the learner to study in detail the surfaces of the planets in a dynamic, interactive way. They can investigate the relative sizes and characteristics of the landscape. This facilitates creating the important sense of "ownership" of the constructed knowledge by the learner, who has control of their learning experience the learning experience (Goforth, 1994). This builds a narrative that the learner can explore on their own terms and curiosity. They can compare the Earth with other planets in numerous aspects, with an approach that is very much like the one used by practicing researchers in planetary sciences. This inquiry-based approach drives students to discover by themselves the uniqueness of planets and our Solar System.

V. Tools

Many of the current leading web frameworks and technologies are open source. As a result, they are open for developers to use, extend, and fix. This project utilizes many tools and open-source web frameworks. The tools and frameworks used in the project are HTML Canvas, JavaScript, WebGL, and SAGE2.

A. HTML Canvas

HTML Canvas [1] is a tool used to draw graphics on a webpage. Users of HTML Canvas have the convenience of moving objects around with the Canvas. HTML Canvas can be made interactive by using JavaScript events. HTML Canvas allows for dynamic and scriptable rendering of shapes, as well as allowing rendering of three-dimensional shapes using WebGL.

VI. JavaScript

JavaScript [2] is a high-level interpreted scripting language that provides prototype based object scripting. Major web frameworks, like Chromium [3] and Webkit [4], have a dedicated JavaScript engine to execute it. JavaScript is an essential part of a lot of web applications, as over 95 percent of the 1.25 billion websites rely on it [5]. JavaScript supports both event driven and functional programming styles. JavaScript is robust, however, it does not include any input or output for graphics, as it entirely relies on a host environment to provide this feature.

A. WebGL

WebGL [6] is a cross-platform JavaScript API used for rendering 2D and 3D graphics without the use of any additional plug-ins. It is fully integrated with current web standards. WebGL elements can be mixed with other HTML elements and composited with other pages or page backgrounds [6]. WebGL 2.0 supports objects for the HTML5 canvas elements.

B. SAGE2

SAGE2 [7] is a complete redesign and implementation of SAGE that uses cloud-based and web-browser technologies. SAGE2 is based on the popular Javascript libraries Node.js [8], ffmpeg [9], poplar [10], image magic [11], and other libraries. It is a cluster-based HTML viewer used for displaying elements across multiple browser windows.

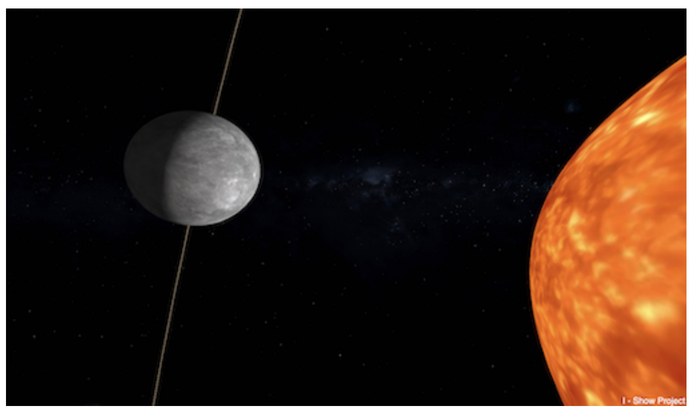

Fig. 6. Mercury

VII. Limitations

As versatile as current modern web languages and technologies are, there still are significant limitations and challenges to them. For users without modern web browser versions, they are limited to what their web browsers can render.

VIII. Roadmap

A. Current Bugs

Currently, there is a persistent issue with displaying the Rings of Saturn.

B. Future Enhancements

Items out of the scope of this project that can be added are visualizing multiple Solar Systems and Galaxies, identifying the time of eclipses and planet transits, Incorporating the red shift effect, and visualizing the expansion of the universe.

C. Future Developments

Future developments include displaying the moons of every planet in the Solar System, rotation and revolution of planets with accurate speeds, visualizing the asteroid belt, and adding additional pop-up features to display the details of each planet.

IX. Discussion

Astronomy and space science are a great use-case for the use of visualization technologies. However, the information student, educator, or space enthusiast may interpret from interacting with models, animations, and simulations of planetary objects does not necessarily reflect the correct scientific view. Harper et al. (2000) discussed the simulation paradigm and pointed out that experiential simulations such as the described VR tour to the planets have a weakness in that too much complexity. This can make learners insecure and lose track of learning objectives. Providing mentoring and carefully constructed activities can let the complexity of the learning environment support active, exploratory learning (Goforth, 1994). The use of images, web sites, programs, and other means that make use of visual information has been increasing in future educational programs (Barab et al., 2001). Using the visual mode of communication requires a different way of teaching, with an emphasis on the process of observation. The combination of this project and 3D-VR models may greatly increase the effectiveness of the learning experience and can guarantee that the student constructs their view of the world in a curious and enjoyable manner.

Acknowledgment

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