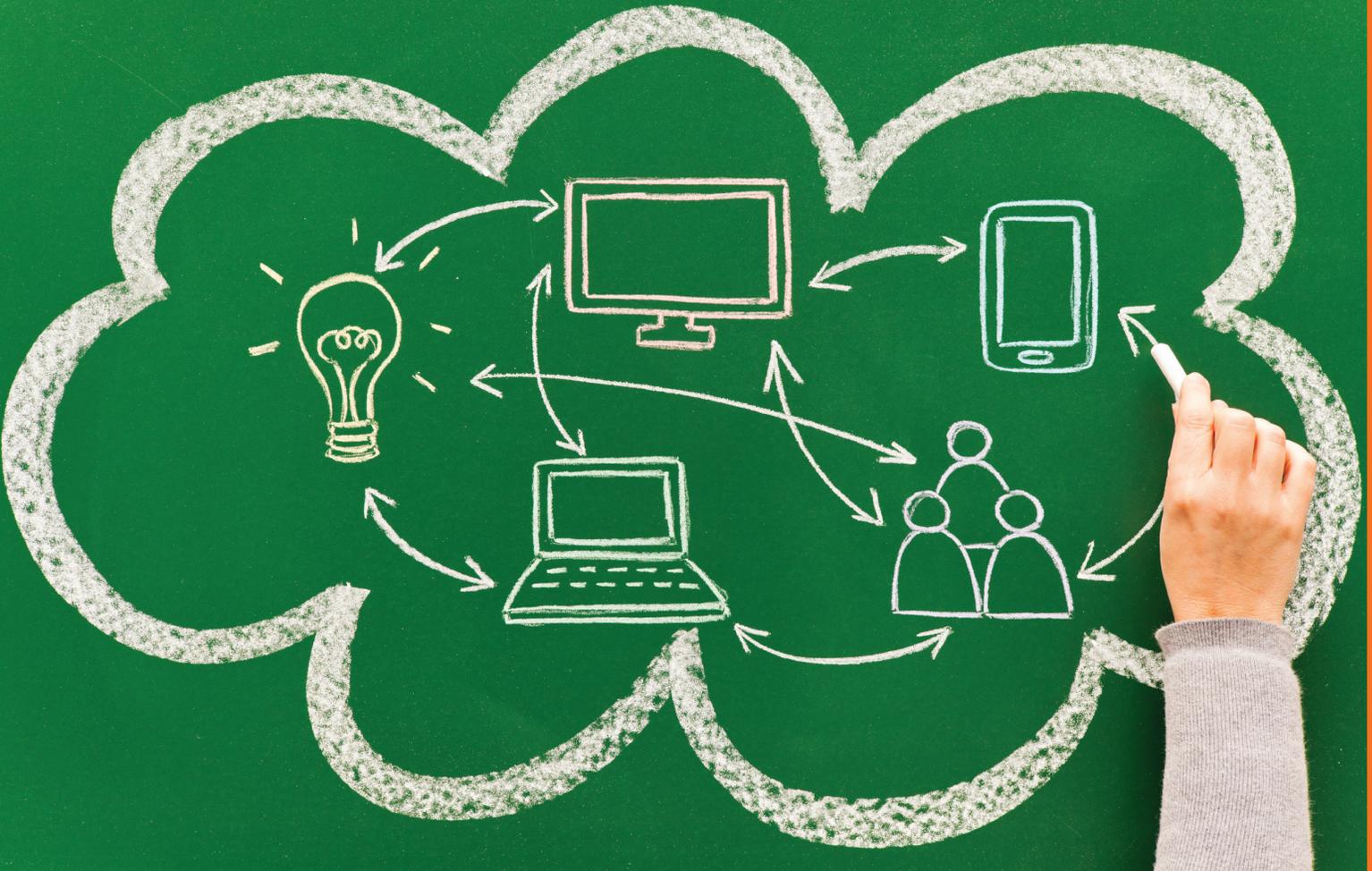


TEXAS SUSTAINABLE ENERGY RESEARCH INSTITUTE



Section 1:

Education

May 30, 2012

CPS Energy
Attention: Paula Miles
145 Navarro
San Antonio, TX 78205

Dear Ms. Miles:

With this letter, the Texas Sustainable Energy Research Institute transmits the following items associated with the **Texas Sustainability Education Project** lead by Dr. Christine Moseley.

SCOPE OF WORK (dated 3/31/2012): “Publish a teacher-friendly database for green education resources”

- Launch the GreenSources Website for public online access and continue development. GreenSources is a searchable and filterable database of community resources scheduled to launch May 2012. It is uniquely structured to allow teachers to identify relevant community resources by type, subject, grade, topic and even educational standard. The purpose is to make community-based sustainability educational resources easily accessible and support student achievement.
- Hyperlink to website: <http://texasenergy.utsa.edu/education/greensources/>

Please share these with your team as appropriate. We invite CPS Energy to contribute relevant material to the website by clicking on the “Organization Login” link located on the GreenSources home page. If you have any questions, please contact Linda Day at (210) 458-8618 or myself.

Kindest regards,



Les Shephard
Director, Texas Sustainable Energy Research Institute



To: Paula Miles
CPS Energy

From: Les Shephard **DATE:** May 30, 2012
Phone: 210-458-7970
E-mail: les.shephard@utsa.edu

Deliverable:

GreenSources Website:

<http://texasenergy.utsa.edu/education/greensources/>

Texas Sustainability Education Project - "Building Community
Partnerships to Promote Ecological Sustainability in Public
Education"

Education > Greensources

GREENSOURCES

Sample text

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ORGANIZATION LOGIN

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Water, Science, and Civics: Engaging Students with Puget Sound, Grades 9-12	Water, Science, and Civics: Engaging Students with Puget Sound, Grades 6-8	Engaging Students in Conservation: Protecting the Endangered Snow Leopard	Climate Change for grades 9-12
Then & Now: Using Aerial Photography To Measure Habitat Change	No Water Off a Duck's Back	Aquatic Times	Climate Change: Connections & Solutions
Buy, Use, Toss	Drop Inside the Edwards Aquifer	Doc Edwards' Amazing Aquifer Adventure!	Activity 5: Water Watchers
Activity 4: My, Look how You've Changed!	Activity 3: All Sorts of Species	Activity 2: Flash Card Frenzy	Activity 1: Reader's Theater

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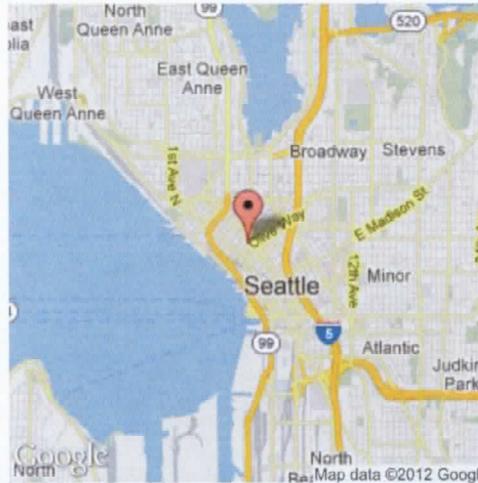
1904 Third Ave., #510
Seattle, Washington
www.facingthefuture.org

Organization Type: Community Outreach
Education

Contact:

Dave Wilton
Assistant Outreach Director
2062641503
dave@facingthefuture.org

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San Antonio, TX 78249

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Education >

WATER, SCIENCE, AND CIVICS: ENGAGING STUDENTS WITH PUGET SOUND, GRADES 9-12

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RESOURCE INFORMATION

Description

<http://www.facingthefuture.org/Home/FTFMembershipLogin.aspx/62/default.aspx?returnurl=/DesktopModules/FTFModules/wfLogDownload.aspx?FileToDownload=4799>

This series of five lessons is available in PDF and SMART Board format. This engaging unit leads your students through an exploration of the significance of Puget Sound and the impact humans have on this valuable resource. Students creatively use technology throughout the unit and the culminating lesson is an action project in which students create a digital public service announcement to educate others about the significance of the Sound and ways to address pollution.

Subject(s):

Science
Social Studies
English/Language Arts

Grade(s):

High School (9-12)

Topic(s):

Citizenship
Water
Human Environment Interactions
Natural Resources

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):


 ORGANIZATION
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ORGANIZATION INFORMATION

[Education >](#)

WATER, SCIENCE, AND CIVICS: ENGAGING STUDENTS WITH PUGET SOUND, GRADES 6-8

[BACK TO EDUCATION FILTER](#)

RESOURCE INFORMATION

Description

<http://www.facingthefuture.org/Home/FTFMembershipLogDownload.aspx?returnurl=/DesktopModules/FTFModules/wfLogDownload.aspx?FileToDownload=4805>

This series of five lessons is available in PDF and SMART Board format. This engaging unit leads your students through an exploration of the significance of Puget Sound and the impact humans have on this valuable resource. Students creatively use technology throughout the unit and the culminating lesson is an action project in which students create a digital public service announcement to educate others about the significance of the Sound and ways to address pollution.

Subject(s):

Science
Social Studies
English/Language Arts

Grade(s):

Middle School (6-8)

Topic(s):

Water
Human Environment Interactions
Natural Resources

NAAEE Guidelines/Strand(s):

Strand 2.4: The Environment & Society
Strand 3.1: Skills for Analyzing & Investigating Environmental Issues

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

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ORGANIZATION INFORMATION

Education >

ENGAGING STUDENTS IN CONSERVATION: PROTECTING THE ENDANGERED SNOW LEOPARD

[BACK TO EDUCATION FILTER](#)

RESOURCE INFORMATION

Description

<http://www.facingthefuture.org/Home/FTFMembershipLogin.aspx?baseurl=/62/default.aspx?returnurl=/DesktopModules/FTFModules/wfLogDownload.aspx?FileToDownload=4040>

This interdisciplinary 1-2 week unit was developed in collaboration with the Snow Leopard Trust. It includes five dynamic lessons and culminates with a service learning project. The unit is designed for 5-8th grade students in science and social studies. Though the lessons are designed as a comprehensive unit, each lesson can stand alone.

Subject(s):

Science
Social Studies

Grade(s):

Elementary (K-5)
Middle School (6-8)

Topic(s):

Citizenship
Ecosystems

NAAEE Guidelines/Strand(s):

Strand 2.2: The Living Environment
Strand 2.4: The Environment & Society

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):


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Education >

CLIMATE CHANGE FOR GRADES 9-12

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RESOURCE INFORMATION

Description

<https://www.facingthefuture.org/Curriculum/PreviewandBrowse/Curriculum/tabid/550/CategoryID/16/List/1/Level/1/Default.aspx>

s two-week curriculum unit for grades 9-12 encourages students to think critically about climate change and to collaborate to devise solutions. Students learn about climate change within a systems framework, examining interconnections among environmental, social, and economic issues.

Subject(s):

Science
Mathematics
Social Studies

Grade(s):

High School (9-12)

Topic(s):

Air, Atmosphere & Climate
Citizenship
Human Environment Interactions

NAAEE Guidelines/Strand(s):

Strand 2.4: The Environment & Society
Strand 3.1: Skills for Analyzing & Investigating Environmental Issues

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

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CLIMATE CHANGE: CONNECTIONS & SOLUTIONS

[BACK TO EDUCATION FILTER](#)

RESOURCE INFORMATION

Description

This two-week curriculum unit encourages students to think critically about climate change and to collaborate to devise solutions. Students learn about climate change within a systems framework, examining interconnections among environmental, social, and economic issues.

Subject(s):

Science
Social Studies

Grade(s):

Middle School (6-8)

Topic(s):

Air, Atmosphere & Climate
Economics

NAAEE Guidelines/Strand(s):

Strand 2.4: The Environment & Society

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Resource Type(s):

- Curriculum

Download(s):

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Education >

BUY, USE, TOSS

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RESOURCE INFORMATION

Description

<http://www.facingthefuture.org/Home/FTFMembershipLoginPage/62/default.aspx?returnurl=/DesktopModules/FTFModules/wfLogDownload.aspx?FileToDownload=4483>

Buy, Use, Toss? is an interdisciplinary unit that includes ten fully-planned lessons. This unit is correlated with national science and social studies standards and will lead your students through an exploration of the system of producing and consuming goods that is called the materials economy. Students will learn about the five major steps of the materials economy; Extraction, Production, Distribution, Consumption, and Disposal. They will also be asked to analyze the sustainability of these steps, determining how consumption can benefit people, economies, and environments.

Subject(s):

Science
Social Studies

Grade(s):

High School (9-12)

Topic(s):

Air, Atmosphere & Climate
Citizenship
Economics

NAAEE Guidelines/Strand(s):

Strand 2.4: The Environment & Society
Strand 3.1: Skills for Analyzing & Investigating Environmental Issues
Strand 3.2: Decision Making & Citizenship Skills
Strand 4: Personal & Civic Responsibility

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

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ORGANIZATION INFORMATION



Texas Parks & Wildlife

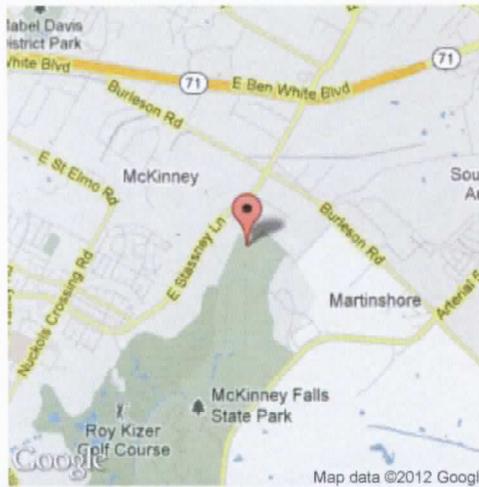
4200 Smith School Road
Austin, Texas
<http://www.tpwd.state.tx.us/>

Organization Type: Parks & Natural Areas

Contact:

Kiki Corry
Project WILD Coordinator
512.389.4369
Kiki.Corry@tpwd.state.tx.us

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Education >

THEN & NOW: USING AERIAL PHOTOGRAPHY TO MEASURE HABITAT CHANGE

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RESOURCE INFORMATION

Description

<http://projectwild.org/documents/ThenandNow.pdf>

Students will compare aerial photographs that are of a community and were taken 50 years apart. They will identify features resulting from human settlement. Using a transparent grid, they will next measure and then discuss changes to wildlife habitat that have occurred over time as a result of human population growth.

Subject(s):

Social Studies

Grade(s):

Elementary (K-5)
Middle School (6-8)
High School (9-12)

Topic(s):

Ecosystems
Human Environment Interactions

NAAEE Guidelines/Strand(s):

Strand 2.4: The Environment & Society
Strand 3.1: Skills for Analyzing & Investigating Environmental Issues

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

- Wildk-12coverjpeg



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NO WATER OFF A DUCK'S BACK

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RESOURCE INFORMATION

Description

Students will (1) identify ways oil spills can adversely affect birds; and (2) describe possible negative consequences to wildlife, people, and the environment from pollutants caused by humans. Students conduct an investigation using water, oil, hard-boiled eggs, detergent, and feathers.

<http://projectwild.org/NoWateroffaDucksBack.pdf>

For more information about this and other Project WILD lessons, activities and teacher workshops please contact your local Texas state coordinator:

<http://www.projectwild.org/TexasCoordinator.htm>

Subject(s):

Science
Social Studies

Topic(s):

Ecosystems
Water

NAAEE Guidelines/Strand(s):

Strand 3.1: Skills for Analyzing & Investigating Environmental Issues

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

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AQUATIC TIMES

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RESOURCE INFORMATION

Description

<http://projectwild.org/documents/AquaticTimes.pdf>

Students investigate, write, and produce a newspaper that features aquatic information and issues.

Background:

The production of a newspaper requires an array of skills that include design capabilities, writing, composition, research, and decision making. This activity provides an opportunity for the students to coordinate newspaper production with information, issues, and recommendations about aquatic organisms and their habitats.

For more information about this and other Project WILD lessons, activities and teacher workshops please contact your local Texas state coordinator:

<http://www.projectwild.org/TexasCoordinator.htm>

Subject(s):

Science
English/Language Arts

Grade(s):

Elementary (K-5)
Middle School (6-8)

Topic(s):

Citizenship
Ecosystems
Water

NAAEE Guidelines/Strand(s):

Strand 2.2: The Living Environment
Strand 3.2: Decision Making & Citizenship Skills



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Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

ORGANIZATION INFORMATION

Subject: <no subject>

Date: Wednesday, May 30, 2012 9:10 AM

From: Linda Day <Linda.Day@utsa.edu>

ORGANIZATION INFORMATION

Edward Aquifer Authority

1615 N. St. Mary's St.

San Antonio, Texas

www.edwardsaquifer.org

Organization Type: Community Outreach Education

Contact:

Sarah Valdez

Education Coordinator

(210) 222-2204

svaldez@edwardsaquifer.org

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EDWARDS AQUIFER
A U T H O R I T Y

Education >

DROP INSIDE THE EDWARDS AQUIFER

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RESOURCE INFORMATION

Description

Follow the journey of water as rain falls and flows from high atop the Edwards Plateau, submerges below the earth's surface, and then resurfaces through springs in San Marcos. Along the way, you'll discover the hydrology and geology of a complex groundwater system and encounter some of the unique species that make this natural resource home.

Subject(s):

Science

Grade(s):

Middle School (6-8)
High School (9-12)
Adult Education (post HS)

Topic(s):

Natural Resources

NAAEE Guidelines/Strand(s):

Strand 2.1: The Earth as a Physical System
Strand 2.2: The Living Environment

Resource Type(s):

- Multimedia
- Informational Materials

Download(s):

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Edward Aquifer Authority

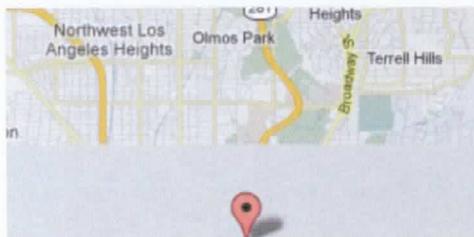
1615 N. St. Mary's St.
San Antonio, Texas
www.edwardsaquifer.org

Organization Type: Community Outreach
Education

Contact:

Sarah Valdez

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DOC EDWARDS' AMAZING AQUIFER ADVENTURE!

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RESOURCE INFORMATION

Description

Join Doc Edwards and his Aquifer Explorers as they take you on an animated and live action adventure through the Edwards Aquifer system. Highlights include the aquifer geology and hydrology as well as the plant and animal species that live there.

Subject(s):

Science

Grade(s):

Elementary (K-5)

Topic(s):

Natural Resources

NAAEE Guidelines/Strand(s):

Strand 2.2: The Living Environment
Strand 2.4: The Environment & Society

Resource Type(s):

- Multimedia
- Informational Materials
- Other

Download(s):

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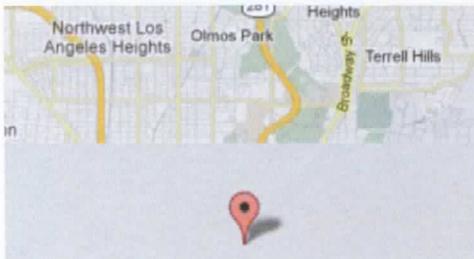
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www.edwardsaquifer.org

Organization Type: Community Outreach
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Contact:
Sarah Valdez

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ACTIVITY 5: WATER WATCHERS

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RESOURCE INFORMATION

Description

Students use facts about water consumption to determine the amount of water used by each individual and the entire community.

Subject(s):

Science

Grade(s):

Elementary (K-5)

Topic(s):

Natural Resources

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Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

- Waterwatchers

ORGANIZATION INFORMATION



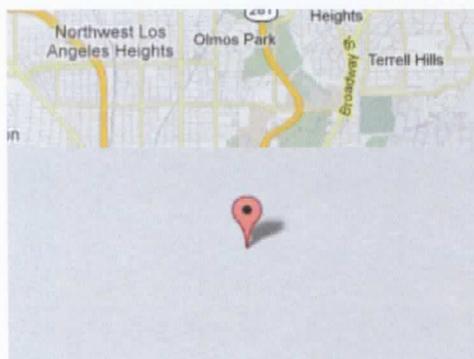
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Contact:
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Education Coordinator
(210) 222-2204
svaldez@edwardsaquifer.org

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ACTIVITY 4: MY, LOOK HOW YOU'VE CHANGED!

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RESOURCE INFORMATION

Description

Students will be able to identify traits of various Edwards Aquifer species. Students will be able to identify adaptive traits and explain reasons why adaptation occurred i.e. why the blind salamander doesn't have eyes. Students will create their own Edwards Aquifer species and be able to explain how their unique traits and adaptations help them thrive in their environment.

Subject(s):

Science

Grade(s):

Elementary (K-5)

Topic(s):

Natural Resources

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Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

- Lookhowyouvechanged

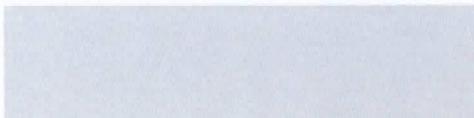
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ACTIVITY 3: ALL SORTS OF SPECIES

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RESOURCE INFORMATION

Description

Students will use Edwards Aquifer Trading Cards to learn facts and figures about species traits and adaptations in relation to their habitat. Students will sort and classify information based on open and directed sorts.

Subject(s):

Science

Grade(s):

Elementary (K-5)

Topic(s):

Natural Resources

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Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

- Allsorts

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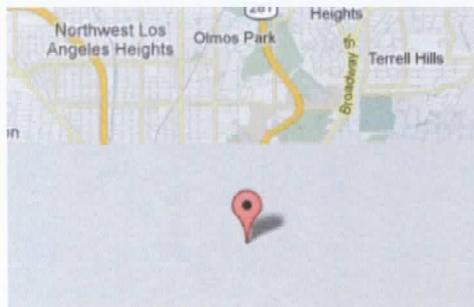
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ACTIVITY 2: FLASH CARD FRENZY

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RESOURCE INFORMATION

Description

Using index cards and the words listed below, have students create vocabulary flash cards for the key terms found in the activity book and video.

Subject(s):

Science
Social Studies

Grade(s):

Elementary (K-5)

Topic(s):

Natural Resources

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

- Flashcardfrenzy

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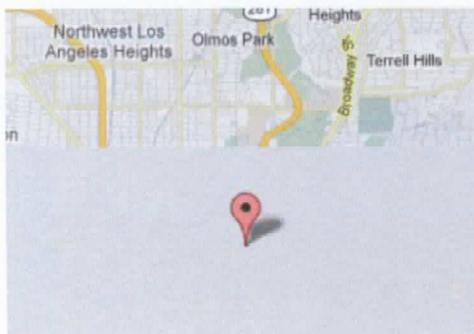
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www.edwardsaquifer.org

Organization Type: Community Outreach
Education

Contact:

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Education Coordinator
(210) 222-2204
svaldez@edwardsaquifer.org

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Education >

ACTIVITY 1: READER'S THEATER

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RESOURCE INFORMATION

Description

Readers' theater demonstrating how the Edwards Aquifer system works.

Subject(s):

Science
Social Studies
English/Language Arts

Grade(s):

Elementary (K-5)

Topic(s):

Natural Resources

Resource Type(s):

- Curriculum
- Lessons & Activities

Download(s):

- Readers Theater

ORGANIZATION LOGIN

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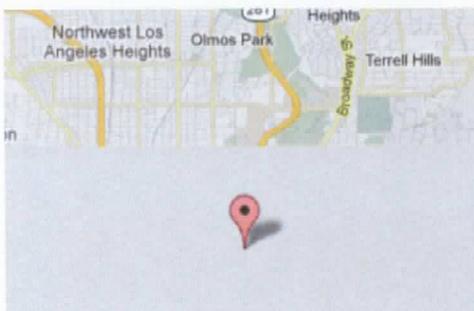
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San Antonio, Texas
www.edwardsaquifer.org

Organization Type: Community Outreach
Education

Contact:
Sarah Valdez
Education Coordinator
(210) 222-2204

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June 21, 2012

CPS Energy
Attention: Paula Miles
145 Navarro
San Antonio, TX 78205

Dear Ms. Miles: *Paula,*

With this letter, the Texas Sustainable Energy Research Institute transmits the following item associated with the **Texas Sustainability Education Project** lead by Dr. Christine Moseley.

SCOPE OF WORK (dated 3/31/2012): "Provide a draft of the Standards Crosswalk in a handout or spreadsheet"

Standards Crosswalk: an alignment of the North American Association For Environmental Education (NAAEE) Guidelines with the Texas Essential Knowledge and Skills (TEKS)

- Although STEM (science, technology, engineering, mathematics) and social studies are at the core of education for sustainable development identifying cohesive units of instruction can be challenging.
- By crosswalking the TEKS with the NAAEE and the college and career readiness standards (CCRS) in science and social studies, we are providing teachers, administrators and informal educators with a valuable tool to connect to local issues of sustainability.

Please share this with your team as appropriate. If you have any questions, please contact Linda Day at (210) 458-8618 or myself.

Kindest regards,

Les
Les Shephard

Director, Texas Sustainable Energy Research Institute



To: Paula Miles
CPS Energy

From: Les Shephard **Date:** June 21, 2012
Phone: 210-458-7970
E-mail: les.shephard@utsa.edu

Deliverable:

Texas Sustainability Education Project:

Standards Crosswalk Handout





NAAEE Annual Conference Proposal Draft

Submission Deadline: April 25, 2012

Proposals must be submitted online.

Before completing your proposal, please be sure to read the [Annual Conference Call for Presentations](#), which describes what reviewers are looking for this year, and explains many of the options below.

To streamline your online submission process, please draft your proposal using this form, save it on your computer, and transfer the information to the online submission form.

To use this form, click **INSIDE the gray boxes and type your entries.**

Tips for Preparing Your Proposal

- Be innovative and creative; this is a competitive process and reviewers are looking for sessions that will push our collective thinking about environmental education.
 - Avoid abbreviations and acronyms that don't clearly explain what the session is about.
 - Comply with word limits. NAAEE might edit your entries for length or clarity.
-

1) Check the strand with which your presentation best aligns:

- Conservation Education
- Food and Agriculture
- Green Schools
- Marine, Bay, and Freshwater Education
- Networking and Leadership Development
- Socioecological Education

2) Check one preferred session format:

- Film Presentation (5–75 minutes)
- Hands-On Presentation (60 minutes)
- Poster
- Roundtable Discussion (60 minutes)
- Symposium (1 hour, 45 minutes)
- Traditional Presentation (20 minutes)
- Traditional Presentation (45 minutes)
- Workshop (Full day)
- Workshop (Half day)

Note: Rooms for all presentations except roundtables and poster sessions are equipped with a PC laptop (with Office Suite loaded), LCD projector, screen, flip chart, and markers. No audio-visual equipment is available for roundtables and posters.

3) Title

- Be sure that your session title clearly describes what the session is about and is no more than 10 words.

GREENSOURCES: RESOURCES FOR ENVIRONMENTAL LITERACY (5WORDS))

4) Summary

- Limit your summary to 40 words. Since your summary is the “marketing pitch” printed in the symposium program to draw symposium participants to your session, we recommend that you use clear and engaging language.

A model for designing online repositories of sustainability education and helping teachers tap into community resources to promote place-based environmental literacy.

5) Description

- Limit your description to 250 words.
- Write in complete sentences and use active verbs to describe the session.
- Describe the specific presentation techniques you will use (interactive, lecture, PowerPoint, etc.) so that participants know what to expect.
- Indicate whether you will provide handouts.

Without a repository of local resources in environmental education, teachers often spend hours on Google sifting through hundreds of resources to find a curricular match. Likewise, community environmental educators often spend (or avoid spending) hours upon hours scouring the state's standards to identify relevant matches with the a state's curriculum. It only makes sense, therefore, to create a central repository of local resources in environmental education that are aligned to school's education objectives. This workshop will present the work of a collaboration of teachers, informal environmental educators and higher ed. to utilize the NAAEE guidelines to identify state standards and create a search matrix for identifying classroom-relevant resources. Through interactive online discussions and activities, participants will explore GreenSources; a Texas-based model for an online repository resources.

6) Internet Access

- NAAEE is working with the conference facility to provide Internet access on a limited basis for breakout sessions (other than Roundtables and Posters). There will be an additional small fee.

Check if you require Internet access for your presentation.

7) Alternative Presentation Format

- Check any formats that you would accept as an alternative to your preferred option.

- Hands-on Presentation
- Poster
- Roundtable Discussion
- Symposium
- Traditional Presentation (20 minutes)
- Traditional Presentation (45 minutes)
- Workshop (Half day Wednesday)

8) Conference Threads

- Select one or two Interest Areas relevant to your presentation. Interest Areas cut across the thematic strands and will be indicated in the conference program. (Optional)

- Arts
- Business/Corporate Sector
- Careers and Young Professionals
- PreK–16 Education
- Research and Evaluation
- Service-Learning

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- Use your session to stimulate thinking about the field of environmental education. For example, highlight why your work is innovative, what you learned, how it supports key trends in the field, and what results you achieved.
- Complete pre-conference planning for your presentation, including consulting with co-presenters (if any), preparing high-quality visuals and handouts, and rehearsing your presentation so that it is interactive and flows, keeping the audience engaged. (Please don't read from notes or PowerPoint slides.)
- Obtain permission or pay appropriate licensing fees if using copyrighted materials, including music.
- Arrive early for your session so that you are ready before the audience shows up. Also end on time so participants can get to the next session.
- Give us at least 72 hours notice in writing at sessioncancellations@naaee.net if there is an emergency and you can't present. We do not want the audience to be left waiting.
- Leave time for questions at the end of your session and include your contact information if someone wants to follow up with you.

I have read and will comply with NAAEE's presenter guidelines.

10) Presenter(s)

List the names of all presenter(s) for your session.

Noah Talerico

Kim Jones

Christine Moseley

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NAAEE Annual Conference Proposal Draft

Submission Deadline: April 25, 2012

Proposals must be submitted online.

Before completing your proposal, please be sure to read the [Annual Conference Call for Presentations](#), which describes what reviewers are looking for this year, and explains many of the options below.

To streamline your online submission process, please draft your proposal using this form, save it on your computer, and transfer the information to the online submission form.

To use this form, click **INSIDE the gray boxes and type your entries.**

Tips for Preparing Your Proposal

- Be innovative and creative; this is a competitive process and reviewers are looking for sessions that will push our collective thinking about environmental education.
 - Avoid abbreviations and acronyms that don't clearly explain what the session is about.
 - Comply with word limits. NAAEE might edit your entries for length or clarity.
-

1) Check the strand with which your presentation best aligns:

- Conservation Education
- Food and Agriculture
- Green Schools
- Marine, Bay, and Freshwater Education
- Networking and Leadership Development
- Socioecological Education

2) Check one preferred session format:

- Film Presentation (5–75 minutes)
- Hands-On Presentation (60 minutes)
- Poster
- Roundtable Discussion (60 minutes)
- Symposium (1 hour, 45 minutes)
- Traditional Presentation (20 minutes)
- Traditional Presentation (45 minutes)
- Workshop (Full day)
- Workshop (Half day)

Note: Rooms for all presentations except roundtables and poster sessions are equipped with a PC laptop (with Office Suite loaded), LCD projector, screen, flip chart, and markers. No audio-visual equipment is available for roundtables and posters.

3) Title

- Be sure that your session title clearly describes what the session is about and is no more than 10 words.

CROSSWALKING: IDENTIFYING THE NAAEE GUIDELINES EMBEDDED IN YOUR STATE'S CURRICULUM (10WORDS)

4) Summary

- Limit your summary to 40 words. Since your summary is the “marketing pitch” printed in the symposium program to draw symposium participants to your session, we recommend that you use clear and engaging language.

A guide for adapting meaningful and engaging EE learning principles identified in the NAAEE guidelines with often rigid test-based standards. (21words)

5) Description

- Limit your description to 250 words.
- Write in complete sentences and use active verbs to describe the session.
- Describe the specific presentation techniques you will use (interactive, lecture, PowerPoint, etc.) so that participants know what to expect.
- Indicate whether you will provide handouts.

One of the most daunting challenges of environmental education today is to develop effective methods and curriculum aligned to increasingly prescriptive test-based standards. The goal is to promote environmental literacy through rich and meaningful learning opportunities in the community while aligning to state educational goals – not always an easy task. This presentation will present the work of a collaboration of teachers, informal environmental educators and higher education faculty to crosswalk the Texas state K-12 and college & career readiness standards with the NAAEE Guidelines to create conduits of instruction for environmental and sustainability education. Through interactive activities, participants will learn how the NAAEE guidelines can serve as much more than an alignment document and provide a framework for effective and transformative environmental education. Participants will also have an opportunity to review the NAAEE and Texas state standards crosswalk and learn how the guidelines can serve as a point of connection between formal and informal educators.

6) Internet Access

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Section 2:

Augmented Reality

Virtual Humans for Data Visualization

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ABSTRACT

Virtual humans have been successfully utilized in many diverse application areas (e.g., medical training, education, and psychotherapy), but they have minimally been used for data visualization. In this paper, the goal was to compare user perception of two approaches to data visualization: 1) a particle-based visualization (i.e., based on the science of energy transfer) as a baseline visualization and 2) virtual human-based visualizations. We integrated these two approaches into a novel augmented reality-based architectural design education application and conducted a user study with 27 3rd and 4th year architecture students. The study compared these two visualization approaches in visualizing a temperature data set for a house. We wanted to determine the impact on user perception of temperature, learning motivation, and perceived learning effectiveness. We hypothesized that participants would have greater temperature estimation error with the virtual humans visualization because of bias derived from empathy experienced with the virtual humans. Surprisingly, results were not what we expected. Our results give insight into user perceptions of these visualizations and some unexpected advantages of using virtual humans for data visualization.

Categories and Subject Descriptors

H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented and virtual realities;

General Terms

Experimentation, Human Factors.

Keywords

Visualization, Virtual Human, Augmented Reality, Tangible User Interfaces, User Study, Education.

1. INTRODUCTION

Virtual humans (VH) have been successfully utilized in many diverse application areas (e.g., medical training[1], education[2]), but to our knowledge, they have never been used for data visualization. Traditionally, data visualization affords user interpretation of data through visual representations, such as points for scalar data, particle traces for vector data [3], and metaphors (e.g., a tree to represent a file structure) for information data [4]. However, these visualizations typically do not attempt to

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elicit emotions or empathy because it may bias the user. However, this bias may be desirable in some cases (e.g., to motivate or enhance memory in advertising or education[5]). VHS may be able to elicit empathy [6], but it has yet to be determined how VH-based visualizations will impact user interpretation of data.



Figure 1. Top: VH-based visualization. Bottom: particle-based visualization.

Hypothetically, VHS may offer a host of novel methods to represent data. VHS have almost unlimited configurations with respect to appearance and animation. That is, they have many multimodal degrees of freedom (e.g., facial shape, rotation and translation of limbs, color, voice), which could be mapped to variables in the data. Then, for example, a variable interacting with another variable (i.e. statistically as in ANOVA) could be represented by social interactions between VHS (i.e., offering social context). VHS offer many data visualization possibilities, which currently have unknown effects on user interpretation. This is what we aimed to investigate in this paper.

Specifically, we conducted a within subjects study that investigated how users perceived a VH based visualization as compared to a particle-based visualization (Figure 1). These were visualizations of temperature data, which was part of an educational simulation of architectural design. The particle visualization was representative of how air molecules move in a house, based on changes in temperature. Similarly, the VH visualization was representative of how humans move in a house, based on changes in temperature.

Thus, we were interested in determining the perceptual effects of these visualizations in our related educational application - Augmented Reality for Passive Solar Energy Education (AR-SEE). AR-SEE is an Augmented Reality application for mobile phones for Passive Solar Energy Education. AR-SEE was designed to provide students both the practical and scientific knowledge about how passive solar energy affects the temperature inside a house. AR-SEE combines a mobile phone-based AR with a physical model of a house. Users interactively change the parameters of the house (e.g., roof style, windows, building materials), which changes the internal temperature inside the house. These changes were visualized through animated visualizations of either particles or VHs in our study.

For the study tasks, participants made changes to the house and estimated the temperature changes based on each visualization. They had to use their perception of the visualizations to configure the house in hottest and coolest configurations. Because our goal was to study perception, we didn't want results to be confounded by participants' prior knowledge or intuition about architectural design (e.g., making the roof larger will provide more shade, which will probably decrease temperature inside the house). To minimize these learning and history confounds, participants were informed that they could not use their intuition or prior knowledge of architectural design because the temperature changes were randomized. That is, their temperature estimations and house configuration choices were based entirely on perception of the visualizations.

We hypothesized that participants would have greater error with the VHs because of participants would empathize with humans. Whereas, we expected that particles would elicit lower error because there would be no empathy or emotional reactions. Participants were able to complete the configuration tasks effectively in both conditions. However, the temperature estimation error results turned out to be quite surprising. That is, although task performance was similar in both conditions, perception of visualization was the opposite of what we expected (see section 5. *Results and Discussion*).

2. BACKGROUND LITERATURE

This section focuses previous work in 1) visualization 2) visualization in AR and 3) Virtual Humans. This section also provides motivation for our choices of study conditions (i.e. VH visualization vs. particle visualization) and the impact on AR.

2.1 Visualization

The purpose of this visualization review is to highlight that 1) Particle based visualizations have been researched for many years, are still being researched, and are thus a relevant choice for a baseline in our study and 2) Metaphors have been used as a basis for designing visualizations but VH-based metaphors have been minimally explored.

2.1.1 Particle-Based Visualizations

Particle-based rendering algorithms[3] are standard visualization methods and there is much recent research that uses these methods. For example, Klein et al. used particles for flow visualization (i.e. vector fields) in 3D. de Souza Filho et al.[7] used particle-based algorithms for tensor field visualization. Similar to our work, Lange et al.[8] used 3D particles to visualize temperature data in buildings. The main point is that particle-based visualization is used actively in current and past research, which makes it a good baseline to compare with new types of visualizations. This is one of the reasons we chose to compare virtual human-based visualization with particle-based visualization in our study.

2.1.2 Metaphors in Visualization

In information visualization, "Visual metaphors map the characteristics of some well-understood source domain to a more poorly understood target domain so as to render aspects of the target understandable in terms of the source." [9] Metaphors have been widely used in information visualization and are still an active area of research. For example, Rahman et al.[10] use a car driving metaphor to visualize online search results of multimedia learning resources.

VH-based visualization could be considered a visual metaphor. However, the effectiveness of VHs as visual metaphors has been minimally explored. We begin to evaluate this in the research presented in this paper/

2.2 Visualization in AR

Visualization is an important topic in AR. The visual modality has traditionally been the primary focus in AR research. Most AR visualization related research has focused on novel interaction techniques, toolsets, or visualization techniques, including: scientific visualization collocated with the corresponding physical area where the data was collected. [11], x-ray vision of buildings and overlaid data visualization [12], AR-based information visualization [13], and visualizing GIS data in situ[14].

There are a few AR visualization papers that present guidelines based on empirical study. Furmanski derived a series of guidelines for visualizing occluded information in AR and found that cutaway techniques can impact the depth perception of the users, in that they perceive virtual objects in the cutaway to be closer than objects in the real world [15].

White and Feiner investigated visualization approaches with handheld AR on a UMPC for visualizing carbon monoxide data in the context of the real world where the data was originally collected. Through user studies, they investigated various methods of representing the data and found that different representations (e.g. spheres versus smoke) elicited different user reactions [16].

Quarles et al. developed and evaluated the augmented anesthesia machine, which visualized a simulation of gas flow and internal components to enhance education and training. They found that combining this visualization with real-machine interaction enabled users to learn more effectively[17].

Visualization is an important area in AR, but there are still major gaps, especially in perception of visualizations in AR. This is the focus of our research.

2.3 Virtual Humans

2.3.1 Virtual Humans for Education

Virtual humans have been very effective in education as instructors and communication skills trainers. Ieronutti and Chittaro used virtual humans as a coach/instructor in an educational virtual environment. The virtual humans explained physical and procedural tasks, allowing learners to receive more practical explanations which are easier to understand. The virtual humans could communicate with students in a natural way by exploiting verbal and non-verbal communications[2]. Takacs and Kiss used virtual humans to enhance a user's ability to learn. By using a photorealistic virtual human, a user's declarative and procedural memory was engaged. The virtual human was able to retrieve data from the physical world and the user, which was used to adjust the VH's mood and expressions [18]. Johnsen et al validated a virtual human for interpersonal skills education. The virtual human presented signs of illness and users interact with it as they would a real human with gestures and speech. Users asked the virtual human a series of questions for diagnosing illness. After each question, the virtual human replies with a pre-defined speech or gesture [1]. According to Paiva et al. [6], VHs can improve learning through evoking empathy, which we expect may have an impact on learning in our AR-SEE application.

2.3.2 Virtual Humans in AR

There has been some work on effectively integrating virtual humans into augmented reality. Balcisoy et al used a virtual human as a representation of computer opponent in an AR Checkers game. The virtual humans had speech, facial and body animations driven by the Checkers game [19]. Vlahakis et al created virtual humans in AR to represent Ancient Olympic athletes at cultural heritage sites. Historical and Bibliographical data were used to make their animations as accurate as possible. The virtual humans could then be seen participating in various Olympic style games in situ with the site [20]. Vacchetti et al investigated real-time interaction between virtual humans and real scenes. The virtual human was used as guide and instructor. Using a head mounted display, users navigated through a building or factory. The virtual human instructed how to use machinery in a factory and guided them through the corridors of a building [21].

The main point is that VHs have been used effectively in many applications. However, to our knowledge, VHs have not been used for data visualization. Given their effectiveness in other applications, we expect that integrating VH's emotional context into data visualization will have benefits to some visualization tasks (e.g., persuasive tasks such as advertising or the task of motivation in education).

2.4 Our Contributions

We propose three main contributions of this paper:

- *VH-Based visualization techniques*: To our knowledge, virtual humans have not been used as a data visualization technique before
- *Factors that affect perception of visualization*: Results of our study provide insight into how users perceive virtual humans and particle visualizations in tangible AR
- *AR-SEE application*: this expands the known uses of AR technology

3. AR-SEE: AUGMENTED REALITY FOR PASSIVE SOLAR ENERGY EDUCATION

The two purposes of this section are to 1) introduce the novel AR-SEE application as a potential use case for VH data visualization and 2) provide a real application context for our study's interfaces, visualizations, and tasks.

This research is based on the AR-SEE project which is an Augmented Reality application for mobile phones for Passive Solar Energy Education. AR-SEE combines a mobile phone-based AR with a physical model of a house. Users interactively change the parameters of the house (e.g., roof style, windows, building materials), which changes the internal temperature inside the house. These changes are visualized through visualizations shown in situ on the phone. The application was designed to provide students the scientific knowledge about how passive solar energy affects the temperature inside the house, which affects energy usage efficiency.

3.1.1 Interaction

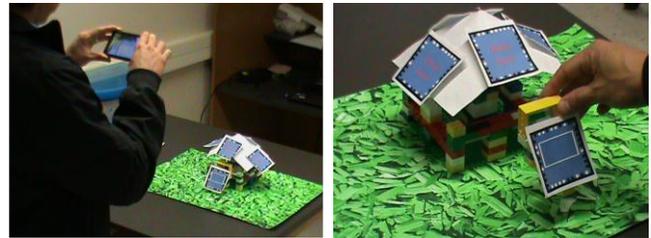


Figure 2. Tangible Interfaces

A user has three complementary ways to interact with AR-SEE (figure 1). Users look through the phone and point it at the big green marker. They can freely walk around and view the simulation. They can physically zoom in to see what is happening inside the house.

The second way of interaction consists of the phone's touch screen interface that includes three buttons located on the right side of the screen and which allow the user to select the material for the roof of the house, the material for the base of the house, and the x-ray button which makes the house partially transparent to allow the user to see either the visualization (e.g., particles or the virtual humans) inside the house.

Users are able to modify the architecture of the house through the tangible interface (figure 2), which consists of small markers to select between two different types of roofs and select from four different types of windows. When the users desire to change the roof or window, they hold the phone with one of their hands, remove one of the small markers and put in another marker with the other hand. As a result, the virtual house will change its architecture according to the marker that is chosen.

3.2 Particle Visualization

The particle visualization (figure 1 bottom) visualizes the Brownian motion effect by using little yellow cubes distributed around the living room in the house. These cubes move around the space of the room with a speed directly proportional to the temperature inside the house. For example, if the temperature is at its highest the particles move faster and when the temperature is at its lowest the particles move slower. Visually, the particles appear to be moving in random directions within the volume of

the house but they bounce off each other and the walls of the house.

However, we made sure to make the changes in speed apparent between temperatures, which can be seen in the results of our study (see section 5 results on configuration tests).

3.3 Virtual Humans Visualization



Figure 3. The animations for one of the virtual humans: chatting, fanning self, wiping brow, dizzy, fallen forward (i.e., fainted). The animations are mapped to increasing temperatures.

AR-SEE also includes animated virtual humans as visualization for temperature data. There are three virtual humans living in the home. They all perform the same animations at the same time, except for one that sits while others are chatting. Five animation states (figure 2) were created for the virtual humans that mapped to temperature level — sitting/chatting (less than 81 degrees Fahrenheit), fanning self (81 to 85 degrees), wiping brow (86 to 90 degrees), dizzy (91 to 95 degrees) and falling forward (above 95 degrees). All of the animations, besides fanning self and wiping brow were purchased from mixamo.com; wiping brow was motion captured using a Microsoft® Kinect and iPi Soft's iPi recorder; fanning self was created manually in 3ds Max 2012.

Each unique animation maps to a specific level of discomfort with sitting and chatting being considered equal. Sitting/chatting where the lowest level of discomfort, followed by fanning self, wiping brow, dizzy and finally, falling forward which was considered the highest level of discomfort. These animations correspond to the same temperature ranges as the particle visualization.

3.4 System Description

The system used in the study consists of the following hardware and software components: 1) Phone: HTC Desire HD (4.3 inch screen, 1Ghz Processor, 768MB RAM, using 1024x768 camera resolution) with Android 2.1, 2) AR: Qualcomm QCAR SDK 1.0 + Unity 3.3. The system runs at approximately 20 frames per second (fps).

4. USER STUDY ON VISUALIZATION PERCEPTION

The objective of this within-subjects study was to investigate how users perceive VH-based visualizations as compared to the more common particle-based visualization as a baseline. Participants progressed through two conditions in random order in which temperature changes were visualized with either: 1) animated virtual humans and 2) particle animation resembling Brownian motion (i.e., how atoms move in different temperatures). Based on visualizations, the estimated the temperature changes and made changes to the house design. The interaction and visualization was enabled through a tangible augmented reality interface and a mobile phone (AR-SEE in section 3).

4.1 Hypotheses

Previous research has shown that VH can elicit user empathy [6]. Thus, we expected that participants would be more empathetic to the virtual humans than the particle visualization. This increased empathy could increase the range of temperature estimation and also increase their motivation to learn with the virtual humans. We also expected the particle visualization to be subject to less empathy driven interpretation, which would afford less error in estimation and performance. Specifically, our hypotheses were:

H1: Users will estimate a wider range of temperature changes when the changes are visualized with animated virtual humans instead of animated particles, leading to greater error in estimation with virtual humans.

H2: Users will perceive that the particles will be more helpful in estimating temperature.

H3: Temperature estimation will take longer with virtual humans than with particles, since the animations take time to play, whereas the particles instantly change vibration when the temperature changes.

H4: There will be no difference in configuration test errors between conditions when users try to find the best and worst configurations. In both conditions, the temperature changes were easy to see.

H5: Users will be more motivated to learn about passive solar energy with virtual humans-based visualizations than with particle-based visualizations.

4.2 Conditions

All participants interacted with both the virtual human visualization (described in section 3) (VIRTUAL HUMAN) and the particle visualization (described in section 2.4.2) (PARTICLE) in random order. There are a few differences between the study application and the AR-SEE application to better control the study. These differences are explained here

Firstly, we wanted to neutralize the effects of prior knowledge in all conditions. Thus, for this study we randomized the effects of changing house parameters on temperature data before the study began, so that participants could not use prior knowledge of passive solar energy or their intuition about passive solar energy. Specifically, there were 2 different temperature data / house design configurations. All participants experienced both configurations, but with different visualizations. For example, if a participant began with Virtual Human visualization and temperature configuration B, then they would interact with particles visualization and temperature configuration A, and vice

versa. Prior to beginning each condition, participants were reminded of the temperature/configuration randomization.

4.2.1 VIRTUAL HUMANS

The virtual humans performed the same as was described in section 3. Prior to beginning this condition, participants were informed how the humans would react to relative temperature changes, but not the exact ranges. There were no other indications of temperature besides the animations.

4.2.2 PARTICLE

Similar to VIRTUAL HUMANS, to visualize temperature, five different temperature ranges were used, which corresponded to five different movement speeds for the particles. In the first level of speed (the lowest, i.e., particles move the slowest possible) the temperature is in a range of less than 80 degrees Fahrenheit. In the following second, a third and fourth level, the temperatures ranges between 80 and 85, 86 and 90 and 91 and 95, respectively. The last level is where one can observe the particles move at their highest speed; this happens when the temperature reaches values more than 95 degrees Fahrenheit. Note that, the particle simulation, while conceptually accurate, is not scientifically accurate with respect to how fast the particles move. Prior to beginning this condition, participants were informed that temperature would affect the speeds, but not the exact ranges. There were no other indications of temperature besides the particle visualization.

4.2.3 Ensuring temperature changes were obvious in both conditions

It is important to note that we aimed to ensure the changes in temperature were apparent to users. The point is that in both conditions we tried to make the particle speeds and the VH animations relatively obvious so that users could easily see the temperature changes and differentiate between them. This can be seen in the results of our study (see section 5 results on configuration tests and subjective feedback).

4.3 Environment and Population

The study was conducted in a quiet, air conditioned laboratory environment. The population consisted of 27 3rd and 4th year undergraduate architecture students 20 to 30 years. The participants had none or very little knowledge AR. Most had moderate knowledge of Passive Solar Energy strategies in architectural design, which is why we randomized the temperature values and told participants not to rely on their previous knowledge. Participants had none or very little knowledge of Brownian motion.

4.4 Procedure

The study took place in one session of 45 minutes broken into 5 phases:

1. *Pre-interview* - established participants' prior knowledge of PSE through a self-rated Likert scale. Demographic information (e.g., age) was also collected.
2. *Interface training* - trained participants on how to interact with the user interface and demonstrated all the functionality of the simulation. The visualization was not displayed during this training.

Phases 3 and 4 were each performed twice, once for each condition:

3. *Directed Interaction: PARTICLES/VIRTUAL HUMANS conditions* - Participants were given verbal instructions to complete a series of simple one step tasks using the touch screen and tangible interfaces. They were told to consider that the initial temperature inside the house was 85°F. A single instruction was given and then participants performed the task. After each instruction that modified the configuration of the house, they had to estimate the new temperature value according to the visualization changes they saw inside the house. There were 9 instructions in all. The instructions were the same in both conditions.
4. *Optimization phase PARTICLES/VIRTUAL HUMANS condition* - During this phase, participants used the same interface from phase three with the particles visualization and were given the task of initially finding the optimal house configuration that makes the temperature inside the house the lowest possible. After that, they had to configure the worst case scenario in which the temperature would reach its highest. Again, they had to find both configurations by checking the visualization inside the house with no other information that could help to complete the task.
5. *Post-interview* - For the interview, the participants were asked to give their opinions on the software. This included a comparison between the two visualization options by using a self-rated Likert scale and explanation to describe the differences.

4.5 Metrics

We employed numerous metrics to assess temperature estimation, time and errors, passive solar energy knowledge, and motivation.

4.5.1 Temperature Estimation

Directed Interaction Temperature Estimation Error (DITEE) – During the two directed instruction tests in phases three and four, after each instruction i was given, the user estimated the temperature $Ev(i)$. At this point, there was a correct temperature value $Cv(i)$ which was directly related to the visualization displayed in the phone's screen (particles movement speed or virtual human behavior). The correct temperature value was not shown on the screen. The user knew that the first temperature for the initial house configuration was 85°F. The estimated value $Ev(i)$ was compared with the previous estimation $Ev(i - 1)$. The difference between these two estimations is called *estimated temperature variation* $ETV(i)$.

$$ETV(i) = Ev(i) - EV(i - 1) \quad (1)$$

For each estimated value, there exists a correct temperature value related to the visualization. Then, the *correct temperature variation* $CTV(i)$ is the difference between the current correct temperature $Cv(i)$ and the previous correct temperature $Cv(i-1)$.

$$CTV(i) = Cv(i) - Cv(i - 1) \quad (2)$$

After user completes each instruction i , there exist two values: the *estimated temperature variation* $ETV(i)$ and the *correct temperature variation* $CTV(i)$. The *Estimation error per instruction* $EE(i)$ is the difference of these two last numbers.

$$EE(i) = ETV(i) - CTV(i) \quad (3)$$

Since the user made nine estimations corresponding to each instruction completed, there are nine *Estimation errors*. Finally, the *Directed Interaction Temperature Estimation Error (DITEE)* was the average of the nine *Estimation errors*.

$$DITEE = \frac{\sum_{i=1}^9 EE(i)}{9} \quad (4)$$

The idea of calculating the error considering the previous estimation is based on the fact that each estimation would be influenced by the previous estimation. Therefore, we used the relative change in temperature ($ETV - CTV$) to calculate the error instead of the raw temperature difference ($E_V - C_V$).

Virtual Human and Particles Effectiveness for Temperature Estimation - Additionally, they were also asked to rate the level of effectiveness of both visualization conditions to estimate the temperature in the house. We used a Likert scale of 1 to 5, 1 being minimally effective, and 5 being very effective.

4.5.2 Time

Directed Interaction Time - participants were given a series of short instructions (e.g., change the roof to a wide configuration). The total amount of time that it took participants to complete the task was logged.

Time for Best Configuration Test and Worst Configuration Test - The amount of time to find the best and worst configurations were recorded. In total, four times were logged: two for particles visualization and two for the virtual human visualization.

4.5.3 Configuration Test Errors

Best Configuration Test and Worst Configuration Test Errors - the correct configurations were determined before-hand. Each one of the configuration options that the participants failed to select correctly counted as an error. Turing each test, errors were logged.

4.5.4 Knowledge

Self-rated Knowledge of Passive Solar Energy - On the first day, participants were asked to rate their level of knowledge of PSE. Then, on the second day, after the optimization phase, participants were once more asked to rate their level of knowledge of PSE. The goal was to see how each interface impacted participants' perceptions of their knowledge on PSE. We used a Likert scale of 1 to 5, 1 being minimal knowledge, 5 being very knowledgeable.

4.5.5 Motivation

Virtual Human and Particles Impact on Motivation - participants were asked two questions (i.e., one for PARTICLES and one for VIRTUAL HUMANS) to rate their level of motivation to continue learning about how the house design impacted the temperature in the house with the virtual human and particle visualizations. We used a Likert scale of 1 to 5, 1 being minimal motivation, 5 being high motivation.

5. RESULTS AND DISCUSSION

Note: Even though Celsius is the scientifically accepted temperature unit, we use Fahrenheit here because it is the unit that the participants used.

5.1 Temperature Estimation

The descriptive statistics of the Directed Instruction Temperature Estimation Error for both PARTICLES and VIRTUAL HUMAN visualizations are shown in Table 1. Using a paired t test, we found a significant difference between the conditions ($t(24) = 3.112$, $p < .05$). The means suggest that participants were more accurate at estimating temperature with virtual humans. *Thus, H1 is rejected.*

Table 1. Directed Instruction Temperature Estimation Error (Mean Fahrenheit degrees)

Condition	Mean	Std. Dev.	Std. Error
PARTICLES	5.06	2.61	0.52
VIRTUAL HUMAN	3.52	1.46	0.29

5-Likert Temperature Estimation Effectiveness: There was no significant difference between the 'Effectiveness of the virtual human condition in helping to estimate the temperature inside the house (mean 3.96) and 'Effectiveness of the particles condition in helping to estimate the temperature inside the house (mean 3.65). A Wilcoxon Signed-rank test shows that there is no a significant effect of Condition ($Z = 0.995$, $p = 0.32$, $r = 0.137$) (Table 2). *Thus, H2 is rejected.*

Table 2. Virtual Human and Particles Effectiveness (Mean Likert scale 1-5)

Condition	Mean	Std. Dev.
PARTICLES	3.65	1.05
VIRTUAL HUMAN	3.96	1.03

5.2 Time

Table 3. Directed Instruction Time (Seconds)

Condition	Mean	Std. Dev.	Std. Error
PARTICLES	254.68	55.33	10.64
VIRTUAL HUMAN	227.76	55.81	10.74

Table 3 shows the mean times to complete the Directed Instruction in both conditions. Note: the time it took for the experimenter to give directions was removed from these results. Using a paired t test, we found a significant difference between PARTICLES and VIRTUAL HUMAN ($t(26) = 2.172$, $p < .05$) with Directed Instruction Time. The means suggest that users spent less time with virtual humans.

Table 4. Best Configuration Test Time (Seconds)

Condition	Mean	Std. Dev.	Std. Error
PARTICLES	114.83	48.25	9.28
VIRTUAL HUMAN	114.57	58.90	11.33

Table 4. Worst Configuration Test Time (Seconds)

Condition	Mean	Std. Dev.	Std. Error
PARTICLES	62.68	39.14	7.53
VIRTUAL HUMAN	67.48	59.09	11.37

Tables 4 and 5 give the mean times for the two conditions when the optimization test was done. The table includes the mean times for finding the best configuration and the worst configuration. We found no significant differences in Configuration Times in both best and worst configurations between PARTICLES and VIRTUAL HUMAN ($t(26) = 0.021$, $p = .98$ and $t(26) = -0.427$, $p = 0.67$). *Thus, H3 is rejected.*

5.3 Configuration Test Error

The means of the *Best and Worst Configuration Errors* are given in Tables 5 and 6. We found no significant differences in either best or worst configurations between PARTICLES and VIRTUAL HUMAN ($t(25) = -0.068$, $p = .94$ and $t(25) = 0.428$, $p = 0.67$). *Thus, H4 cannot be rejected.* In general, errors were very low in both conditions. From this we can conclude that both methods were

effective in visualizing relative temperature change.

Table 5. Best Configuration Test Error (Fahrenheit degrees)

Condition	Mean	Std. Dev.	Std. Error
PARTICLES	1.76	3.79	0.74
VIRTUAL HUMAN	1.84	3.98	0.78

Table 6. Worst Configuration Test Error (Fahrenheit degrees)

Condition	Mean	Std. Dev.	Std. Error
PARTICLES	1.42	3.54	0.69
VIRTUAL HUMAN	1.07	2.59	0.50

5.4 Motivation

There was a significant difference between the ‘Motivation to learn about the effect of the house design on temperature when using the virtual humans (mean 4.5) and ‘Motivation to learn about the effect of the house design on temperature when using the particles visualization’ (mean 3.8). (Table 7) Thus, H5 cannot be rejected.

Table 7. Virtual Human and Particles Impact on Motivation (Mean Rank Likert scale 1-5)

Condition	Mean	Std. Dev.
PARTICLES	3.8	1.09
VIRTUAL HUMAN	4.3	0.7

A Wilcoxon Signed-rank test shows that there is a significant effect of Condition ($Z = -2.65$, $p < 0.05$, $r = 0.36$). This result was supported by the post-study interview in which most of the participants expressed preference by the human visualization because it is considered more realistic than particles. In addition, during the interaction the users showed sympathy with the reactions of the virtual humans by smiling, laughing or showing expressions of having fun.

5.5 Learning Effectiveness

Participants perceived that they learned something about passive solar energy, even though we told them truthfully that the house design interactions and their effect on temperature. The means of Self rated knowledge of passive solar energy before and after were 2.88 and 3.30, respectively (Table 9). A Wilcoxon Signed-rank test shows that there is a significant effect of Condition ($Z = -3.051$, $p < 0.05$, $r = 0.42$). This suggests that the simulation we developed increased the user’s self-perception of their level of PSE knowledge.

Table 9. Self-rated Knowledge of PSE (Mean Likert scale 1-5)

Condition	Mean	Std. Dev.
PARTICLES	2.88	0.71
VIRTUAL HUMAN	3.3	0.61

5.6 Discussion

Temperature Estimation Error: Even though the VHs seemed to elicit more emotional responses (i.e., we observed this anecdotally in the videos), surprisingly, results showed that users’ estimations of the temperature were significantly more accurate in the VIRTUAL HUMANS condition. We expect that the participants could relate to human reactions to the temperatures inside the

house based on their personal previous experiences or feelings. That is the changes were easier to identify because the animations were more familiar, memorable, and expressive, which made them more consistently identifiable for temperature estimation..

5-Likert Temperature Estimation Effectiveness: Although, participants did not measurably perceive this consistency, since neither of the two visualizations were considered to be significantly more effective for temperature visualization. That is, it is unclear if people prefer PARTICLES or VIRTUAL HUMANS for estimation. There was no clear agreement on this even though the VHs provided more consistency (i.e., lower error) for temperature estimation.

Although, comments like "I like to see the human, but particles are more distinctive", or "People’s reaction are more interesting but since particles occupied more space, I could estimate the temperature easier" were provided for people that thought particles were more effective. Contrarily, students who supported the effectiveness of Virtual Human gave comments like "Comparing attitudes makes it easier to compare temperatures", "Humans are easy to read" and "It is clear how their feelings were".

Directed Instruction Time: Participants took less time to complete the directed instruction in the VH condition. When the users changed something in the particles condition, it either took them more time to perceive the particle speed changes. Also they had to move closer to the scenario in order to see the differences in the speed of the particle movement (i.e. based on our anecdotal video observations).

Configuration test times: Contrary to directed instruction time, there were no significant differences in the configuration test times. That is, participants must have become familiar with the particle speed changes. This could indicate that the particles present a higher learning curve for perception. In contrast, this highlights one advantage of the virtual humans in that, users very quickly understood what the virtual humans were trying to convey in their animations due to their familiarity with human reactions to heat.

Configuration Test Error: Similarly, there were no significant differences in configuration test errors (i.e., not the same as temperature estimation error). Although we cannot say that this result is the same in both conditions, we think it is likely that they are very close considering the p-values were quite high (e.g., $p = .94$ and $p = .67$) and the averages were very similar. That is, performance wise, VHs and particles yielded similar, low error results. Qualitatively, both visualizations typically enabled users to successfully complete the task.

Motivation: As expected, the virtual human visualization had a significant impact on users in their motivation to learn more about PSE. The quantitative data was backed by the qualitative post-interview in which many participants expressed their preference for this condition. The participants expressed ideas like: "People are easier to understand because I know what the people feel cause we feel in the same way" (i.e., VHs can elicit empathy) and "It is funny to see the reactions of people".

Learning: Most participants had previous knowledge about architectural elements in PSE, but the results still showed a positive impact on their learning. Even though participants were informed that the temperature changes were random, they became more aware of house design issues that impact on PSE.

Other observations: In addition, some of them expressed preference for a touchscreen interface instead of a combination of tangible and touchscreen interfaces. Therefore, an interesting study would be to test the application and their different types of visualization with people who have minimal knowledge about PSE to test their attraction for the tangible interface and its impact in combination with the visualizations.

6. CONCLUSION

The presented VH-based visualization is a novel idea - researchers have not previously used VHS for data visualization. Thus, this paper represents the first steps into this area. Our study unexpectedly revealed advantages for VH-based visualization. We were surprised that the VH-based visualization both increased motivation (i.e., as expected) and enabled significantly lower temperature estimation error than the particle visualization (i.e., the opposite of what we expected, based on the bias brought on by empathetic characters[6]). That is, although participants did seem to experience empathy with the VH visualization, as compared to the particles, which did not seem to elicit empathy, VH-based visualization maintained relatively low error in perception.

Lessons learned: 1) *Errors in Perception:* as compared to the particles-based visualization VH-based visualization maintained relatively low error in perception. 2) *Learning time:* Even though VH animations take longer to play than the particle movement, the user's familiarity with human action may enable a shorter learning time than particles, when learning how to interpret the VH-based visualization. 3) *Perceived Effectiveness:* Users may not consistently perceive performance advantages (i.e., lower error, more consistent estimation, faster learning time) of VH. 4) *Motivation:* In general, VH-based visualizations can increase motivation for learning in tangible AR environments.

7. FUTURE WORK

In the future we plan to determine the scalability of VH-based visualization with multi-dimensional data sets and to discover the resulting perceptual thresholds for animations. Ultimately, we aim to provide guidelines for the use of VHS in data visualization.

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9. REFERENCES

- [1] Johnsen, K., A. Raij, A. Stevens, D.S. Lind, and B. Lok. *The validity of a virtual human experience for interpersonal skills education*. 2007: ACM.
- [2] Ieronutti, L. and L. Chittaro, *Employing virtual humans for education and training in X3D/VRML worlds*. Computers & Education, 2007. **49**(1): p. 93-109.
- [3] Hansen, C.D. and C.R. Johnson, *The visualization handbook*. 2005: Academic Press.
- [4] Card, S.K., J.D. Mackinlay, and B. Shneiderman, *Readings in information visualization: using vision to think*. 1999: Morgan Kaufmann.
- [5] Bridge, D.J., J.Y. Chian, and K.A. Paller, *Emotional context at learning systematically biases memory for facial information*. Memory & cognition, 2010. **38**(2): p. 125-133.
- [6] Paiva, A., J. Dias, D. Sobral, R. Aylett, S. Woods, L. Hall, and C. Zoll, *Learning by feeling: Evoking empathy with synthetic characters*. Applied Artificial Intelligence, 2005. **19**(3-4): p. 235-266.
- [7] de Souza Filho, J., M. Renhe, M. Vieira, and G. de Almeida Leonel, *A Viewer-dependent Tensor Field Visualization Using Multiresolution and Particle Tracing*. Computational Science and Its Applications-ICCSA 2012, 2012: p. 712-727.
- [8] Lange, B., N. Rodriguez, W. Puech, H. Rey, and X. Vasques. *A 3D particle visualization system for temperature management*. 2011.
- [9] Risch, J.S., *On the role of metaphor in information visualization*. Arxiv preprint arXiv:0809.0884, 2008.
- [10] Rahman, A. and A. El Saddik. *Mobile based multimodal retrieval and navigation of learning objects using a 3D car metaphor*. 2011: ACM.
- [11] Silva, R., P.S. Rodrigues, J.C. Oliveira, and G. Giraldi. *Augmented Reality for Scientific Visualization: Bringing Datasets inside the Real World*. 2004: Citeseer.
- [12] Bane, R. and T. Hollerer. *Interactive tools for virtual x-ray vision in mobile augmented reality*. 2004: IEEE Computer Society.
- [13] Slay, H., M. Phillips, R. Vernik, and B. Thomas. *Interaction modes for augmented reality visualization*. 2001: Australian Computer Society, Inc.
- [14] Liarokapis, F., I. Greatbatch, D. Mountain, A. Gunesh, V. Brujic-Okretic, and J. Raper. *Mobile augmented reality techniques for GeoVisualisation*. 2005: IEEE.
- [15] Furmanski, C., R. Azuma, and M. Daily. *Augmented-reality visualizations guided by cognition: Perceptual heuristics for combining visible and obscured information*. 2002: IEEE.
- [16] White, S. and S. Feiner. *SiteLens: situated visualization techniques for urban site visits*. 2009: ACM.
- [17] Quarles, J., P. Fishwick, S. Lampotang, I. Fischler, and B. Lok, *A mixed reality approach for interactively blending dynamic models with corresponding physical phenomena*. ACM Transactions on Modeling and Computer Simulation (TOMACS), 2010. **20**(4): p. 22.
- [18] Takacs, B. and B. Kiss, *The virtual human interface: A photorealistic digital human*. Computer Graphics and Applications, IEEE, 2003. **23**(5): p. 38-45.
- [19] Balcişoy, S., R. Torre, M. Ponder, P. Fua, and D. Thalmann. *Augmented reality for real and virtual humans*. 2000: IEEE.
- [20] Vlahakis, V., J. Karigiannis, M. Tsotros, M. Gounaris, L. Almeida, D. Stricker, T. Gleue, I.T. Christou, R. Carlucci, and N. Ioannidis. *Archeoguide: first results of an augmented reality, mobile computing system in cultural heritage sites*. 2001.
- [21] Vacchetti, L., V. Lepetit, G. Papagiannakis, M. Ponder, P. Fua, D. Thalmann, and N. Magnenat-Thalmann. *Stable real-time interaction between virtual humans and real scenes*. 2003: IEEE.

AR-SEE: Mobile Phone Augmented Reality for Passive Solar Energy Education

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Organization or School

ABSTRACT

We describe and evaluate a novel application of mobile phone AR: passive solar energy education (AR-SEE). The goal of AR-SEE is to enable students to learn about the science behind architectural design – how passive solar energy affects internal temperature and energy usage efficiency. For the limited performance capabilities of mobile phone AR, this application addresses the challenge of combining simulations (computationally intense simulation and real time simulation), interaction modalities (2D GUI touch screen and 3D tangible interfaces) and visualizations.

We conducted two pilot studies and with 9 local teachers and 13 high school students resulting in three development iterations, and a between-subjects user study with 36 college students that assessed usability and learning outcomes. Results of our studies give insight into user perceptions, usability, and impact on learning with mobile phone AR for educational simulation.

KEYWORDS: Augmented Reality, Visualization, Tangible User Interfaces, Simulation, Usability, Education.

INDEX TERMS: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented and virtual realities;

1 INTRODUCTION

Conceptually, AR is an attractive modality to use for education, since AR can provide unique perceptual (e.g., overlaid visualization) and interactive (e.g., tangible interfaces) benefits, which in some cases have had a positive impact on learning [1, 2]. The most widely available way to provide these benefits to students is through mobile phone AR, since currently many students already have AR capable phones. However, there are a number of technical and usability issues that may impact learning effectiveness. For example, phone size and computing power may be considered two of the major technical limiting factors on mobile phone-based AR. These limitations may be especially significant for AR applications with more complex visualization needs. Consider an educational AR visualization of passive solar energy (figure 1). Passive solar energy deals with using the energy from the sun without using any collectors, grids, or cells, such as solar panels. Hence, the purpose of this interactive visualization is to educate students about energy efficient architectural design and the science behind it (i.e., Brownian motion). The physical screen size, computational power, and interaction techniques of the phone could significantly impact usability and learning effectiveness, which are the primary topics this research aims to investigate.

Specifically, we investigate these issues in a novel test-bed application: a mobile phone-based AR module for passive solar

energy education (AR-SEE) (figure 1). The educational goal is to teach students about the relationship between architectural design (e.g., choices in house material, window size and placement, house orientation to the sun) and the underlying science (e.g., passive solar energy, energy transfer and conversion). From a practical perspective, these design choices affect energy efficiency and temperature in the home. These concepts are usually taught through lectures, textbooks, or hands-on experimentation, but the relationship between these concepts is not effectively visualized.



Figure 1. AR-SEE: mobile phone AR for passive solar energy education

To address this, AR-SEE integrates 1) visualizations of a solar simulation and a Brownian motion simulation 2) a combination of 2D GUI and tangible AR interfaces, and 3) a computationally complex architectural design simulation. AR-SEE enables users to modify passive attributes of a virtual model house (e.g., materials, window size, tree placement and many other variables). Changing these attributes affects the amount of solar energy stored within the house and the temperature. AR-SEE shows an interactive

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visualization of this process in situ with the virtual model house (figure 1). Ultimately, we aim to use AR-SEE to enable novel interaction and visualization approaches to passive solar energy education. To achieve this goal, the usability of the AR-SEE must be studied and refined.

We have conducted 1) two pilot usability studies with nine local teachers and 13 local high school students and 2) a user study with 36 college students to investigate how the usability of AR impacts learning. These studies have 1) enabled us to improve the design and usability of the system in three development iterations, 2) given us insight into the effects of mobile phone AR in learning.

1.1 Current Passive Solar Energy Education

In traditional settings, students may read a book to learn about the science behind passive solar energy. Although this is a widely used approach, it lacks in terms of motivation and direct learner engagement [3]. A newer, more hands-on approach is to have the students construct a simple cardboard model of a house and perform various experiments with it. This involves using heat lamps to represent the sun, adding windows, changing house orientation, and tracking internal temperature changes of the model house [4]. While this is a more engaging approach to teaching practical passive solar energy concepts, it is still difficult for students to understand the underlying science processes, such as energy transfer and conversion, since these processes are invisible. We expect that the combination of tangible AR, visualization, and the model house will maintain the benefits of hands on learning, and potentially enhance student understanding of the underlying science of passive solar energy.

2 PREVIOUS WORK

There has been a significant amount of previous research that is relevant to the research presented in this paper. Specifically, this section focuses on 1) AR on handhelds and mobile phones, 2) AR in education, 3) AR in architecture 4) AR in visualization.

2.1 AR on Handhelds and Mobile Phones

Rohs overviews three handheld AR games and discusses the approach to interaction, which in some cases has both button pressing and 3D interaction (e.g., rotating the phone to aim a kick for a soccer game)[5].

Schamlstieg and Wagner note that the magic lens metaphor afforded by the phone has some specific limitations, due to limited field of view and tracking constraints. They suggest that application designers should design to limit movements during the AR experience.[6]

Henrysson investigated several techniques for mobile phones to manipulate virtual objects. For example, users moved a single virtual object by moving the phone, hitting buttons, or moving a tracked marker. They found that tangible interfaces had some advantages for certain operations and button pressing had some advantages in others [7].

2.2 AR in Education

In chemistry education, AR was evaluated for building molecular bonds. Different people perceive different benefits of tangible AR versus viewing physical models (i.e., with balls and sticks to represent the molecules and bonds. Different people perceive different benefits of tangible AR versus viewing physical models (i.e., with balls and sticks to represent the molecules and bonds [8]. In general, tangible AR was not found to be very usable, largely due to errors caused by the tracking system[9].

In geometry education, Kaufmann developed a 3D immersive see through AR application using head mounted displays. Users

interacted with a personal interaction panel – a menu driven 6dof tracked handheld panel that also had 3D interaction [10].

Shelton et al created an animated AR based simulation to demonstrate how the earth orbits the sun and how it rotates on an axis. They performed a study with 34 geography students. The results showed that AR was generally acceptable by students but there were some perceptual issues from the 3D perspective and the single marker.[11]

Nischelwitzer et al developed an AR enhanced book that taught children about the layout and basic purpose of the human alimentary system with 3D interactive animated graphics. They found significant learning benefits over a standard textbook.[12]

O'Malley reviewed many educational technologies that involved tangible UI, and highlighted educational benefits of tangible interfaces to hands-on learning approaches [13].

2.3 AR in Architecture

There is a rich history between augmented reality and architectural design. AR has merged virtual designs with real construction sites, and has enabled new types of interactions that enhance the design process. As one of the earliest examples, Webster et al developed an early prototype of an AR system for architectural construction, inspection, and renovation. It used an optical see through display to afford users x-ray vision of the internal structures of buildings [14]. Behzadan et al developed a hardware and software framework for visualization of construction processes (e.g., machinery placement) for construction sites [15]. Wang et al have compiled an extensive review of using mixed reality in architectural design and construction [16].

2.4 AR in Visualization

Visualization is an important topic in AR. The visual modality has traditionally been the primary focus in AR research. However, Zhou et al. reviewed past ISMAR publications on visualization and found this topic to be relatively under studied in terms of papers published [17]. We have found this to be true of other publication venues in our literature searches, which demonstrate the need for more research into AR visualization.

Most AR visualization related research has focused on novel interaction techniques, toolsets, or visualization techniques, including: magic lenses [18], scientific visualization collocated with the corresponding physical area where the data was collected. [19], x-ray vision of buildings and overlaid data visualization [20], AR-based information visualization [21], and visualizing GIS data in situ [22, 23].

There are a few AR visualization papers that present guidelines based on empirical study. Furmanski derived a series of guidelines for visualizing occluded information in AR and found that cutaway techniques can impact the depth perception of the users, in that they perceive virtual objects in the cutaway to be closer than objects in the real world [24].

White and Feiner investigated visualization approaches with handheld AR on a UMPC for visualizing carbon monoxide data in the context of the real world where the data was originally collected. Through user studies, they investigated various methods of representing the data and found that different representations (e.g. spheres versus smoke) elicited different user reactions [25].

Quarles et al. developed and evaluated the augmented anesthesia machine, which visualized a simulation of gas flow and internal components to enhance education and training. They found that combining this visualization with real-machine interaction enabled users to learn more effectively[1].

2.5 Our Contributions

The review of previous work highlights several gaps in knowledge that the present research is attempting to address. Specifically, our main contributions are:

- A novel mobile AR application for passive solar energy education (see section 3).
- An approach to enable interactive simulations with a combination of computationally intensive simulations and real time simulations on mobile phone AR (See section 3.6). We have found minimal prior work in AR to inform our approach.
- Insight into the impact of interface usability on learning through an empirical comparison between desktop PC, touch screen interaction on mobile phone AR, or a mix of tangible and touch screen interactions on mobile phone AR (see sections 4 and 5).

3 AR-SEE PROTOTYPE

Here we describe the development of the AR-SEE prototype. The purpose of AR-SEE is to teach the following concepts: 1) the scientific concepts behind passive solar energy and 2) practical concepts of architectural designs that utilize passive solar energy. These educational goals largely drove development and design decisions of the AR-SEE prototype. This section explains the technical challenges that we faced in two iterations of development of AR-SEE and describes our resulting approach to visualization, interaction, and simulation.

3.1 Example Use Case

To demonstrate a typical user experience with AR-SEE this section describes one use case scenario where the user has a specific task to perform. The user is tasked with finding the optimal temperature of a house using only passive (i.e., not using an air conditioner) changes to the house (e.g., changing tree placement, window material, roof size and/or material). The task takes place in the summer in a hot and dry climate.

The user looks through the phone at the markers and sees an overlaid house. Inside, there is a visualization of thermal energy (i.e., energy transfer and conversion on the atomic level) that changes based on the simulated internal temperature of the house. As the temperature condition inside the building increases, atoms, represented as particles, move faster and appear brighter. Energy savings and total cost per month is also displayed.

Then the user increases the size of the roof, which causes the internal house temperature to decrease. This is accomplished by physically swapping the roof marker that rests on top of the house with a secondary roof marker. Concurrently, the atoms representing the air volume in the house slow down and become less bright. To further cool down the house, the user interacts with buttons on the phone's touch screen to change house material and roof material. The user can also modify the size of the window; like the roof, this too is accomplished by physically swapping a marker. In this case, the marker is attached to a Lego block designed to look like a window. By swapping the marker/block combination, the window changes appearance. Then the user may change the time of day (i.e. to affect the position of the sun) and visualize the effect of the current configuration on the house's temperature. There are many other variables that the user could change to affect the internal temperature, but this subsection describes only one example.

3.2 Implementation Approach Overview

To enable use cases similar to the one in section 3.1, simulations, interaction techniques, and visualization components must be combined. First, prior to runtime, a series of computationally

intensive (not real-time) architectural simulations are performed. Each simulation outputs the expected temperature for a given house configuration (e.g., building material, orientation relative to the sun, window placement) at discrete time intervals (i.e., 6 am, 9 am, 12 am, 3 pm and 6pm). The resulting data is stored on the phone and accessed during runtime to enable 1) interactive visualizations of heat energy and light 2) real-time simulation of energy transfer and conversion, and 3) interactive changes to housing parameters (materials, window size, etc) using a combination of 2D touch interaction and 3D tangible interaction.

3.3 System Description and Performance

AR-SEE consists of the following hardware and software components: 1) Phone: HTC Desire HD (4.3 inch screen, 1Ghz Processor, 768MB RAM, using 1024x768 camera resolution) with Android 2.1, 2) AR: Qualcomm QCAR SDK 1.0 + Unity 3.3. The prototype runs at approximately 20 frames per second (fps). Performance issues are discussed in the following sections.

3.4 Computationally Intense Architectural Simulation

Architects have specialized simulation tools to aid in design decisions. Our co-author, who is an architecture expert, utilized the building performance software package IES VE-Pro [26]. IES-VE Pro is a powerful, flexible and in depth suite of building performance analysis tools. This tool provides realistic simulations that cannot be computed in real time on a PC, let alone on a cell phone. Thus, our approach was to run a series of simulations at discrete points in time for a standard base-line house in a hot and dry climate during the summer in southern United States.

The base-line house model used in this study represents a prototype of a single-family house. To simplify the simulation process, the house was simulated as one space with a square plan with one window (20% of the façade area) on the south-facing facade. Performance metrics simulated were average space temperature and comfort index. Although the prototype only uses the summer solstice simulation in the initial evaluation, we simulated the winter solstice and both the vernal and autumnal equinoxes. These are peak temperature times in the year, which would likely be most effective to demonstrate the differences.

A parametric analysis was conducted, which included changing the values of selected building characteristics to evaluate the impact on the performance metrics mentioned above. Building characteristics modified include: glazing size and orientation, existence and size of shading devices, glazing type, wall/room thermal resistance (R-values), and wall roof exterior finish materials. In all, 45 scenarios were simulated.

3.5 Real-time Simulation and Visualization

This section describes the visualization of the real time component of the light and heat energy simulations. The purpose of this section is to provide insight into integrating these types of simulations with mobile phone AR.

3.5.1 Energy Transfer and Conversion

The energy visualization inside the house (figure 2) approximates Brownian motion, which describes the physical motion of thermal energy particles (i.e., molecules) in the air according to the temperature in the environment, and as impacted by processes of energy transfer and conversion. That is, at lower temperatures in a given volume, each atom in the air moves more slowly. At higher temperatures the atoms move faster.

We approximated Brownian motion as a particle system within a volume (e.g., a cube) in which the particles all move at a

constant speed and collide with all other particles. For more than 50 particles, the fps noticeably decreases (Table 1).

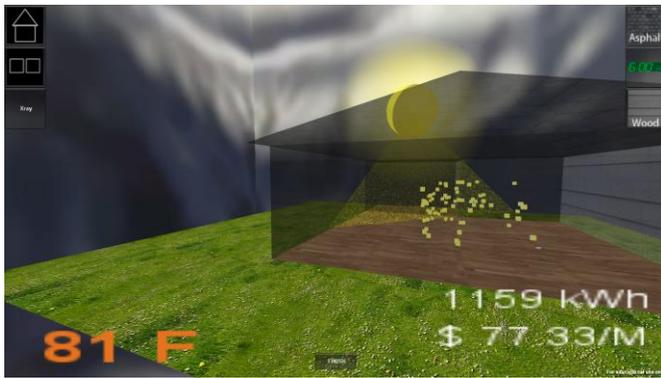


Figure 2. The Energy Transfer and Conversion Visualization - (from Unity 3.3 on PC for clarity) Users can choose to make the house transparent to make it easier to see the particles

Table 1. Performance with particle collisions

Number of particles	FPS
0	22-28
25	20-25
50	18-23
72	15-20
144	7-12

To enable a higher number of particles, we implemented a version that does not use collisions. We noticed that due to the size of the screen, the phone would have to be extremely close to the visualization for the user to observe any collision behavior. Instead of collisions driving the direction of movement, we implemented semi-random displacement of the particles. The fps does not decrease at all until we have more than 200 particles. However, if there are too many particles, the scene appears visually cluttered. In the study, we used this version of the simulation without collisions and with 72 particles.

3.5.2 Solar Visualization



Figure 3. Solar Visualization (from Unity 3.3 on PC for clarity)

The purpose of the solar visualization (figure 3) is to demonstrate how the position of the sun in the sky impacts the temperature of the house. The energy and light that comes from the sun here is visualized as animated energy emanating in the direction of the house. The direction of these rays is determined by the vector from the sun to the house. This vector is also used in

a directional light to visualize light and shading at each of the discrete times in the day. For the prototype, the sun's arc through the sky on the summer solstice is interactively (i.e., user controlled) visualized at discrete times of day: 6 am, 9 am, 12 am, 3 pm and 6pm. Based on this discrete times approach using the pre-computed architectural simulation output, the solar visualization has minimal impact on fps.

3.5.3 GUI Touch Screen Interface

Our approach to the GUI (seen in figure 1) was 1) to maximize screen real estate to keep the user's focus on the visualizations. To maximize screen real estate, the interface is usually hidden, except for buttons on the sides of the screen. When a user touches a button, additional buttons appear alongside it. These buttons allow the user to make changes to the configuration of the house. This interface approach utilizes most of the screen for the visualization, rather than the interface.

Towards intuitiveness, the 2D GUI enabled primarily 2D tasks, which may have been less intuitive to implement with a 3D tangible interface or would seem to have little additional benefit as a 3D task. An example of a 2D task was picking the material of the house, such as vinyl siding or brick. The one exception to this rule was a button that changed the relative orientation of the house relative to the sun (see section 4).

3.5.4 Tangible AR Markers Interface



Figure 4. AR-SEE Tangible interfaces.

In the final prototype, there are several tangible objects being tracked (figure 4): 1) two types of windows, 2) three types of roofs and 3) all the other objects (e.g., house, sun, etc.). Both the roof and window are represented by two markers each - standard and wide markers for the roof and large single and small double for the window. These markers act like toggle buttons. Once a marker is found by the camera, it disables the previous roof or window that was selected and replaces it with the roof or window associated with the current marker in view. All other objects are attached the large image marker (i.e., the large green image marker in figure 4). This is the only marker used for 6dof registration in that all virtual models in the scene are attached to the marker. (i.e., their positions and orientations are computed relative to the large image marker).

3.6 Discussion: Integrating a Computationally Intensive Architectural Simulation into Mobile AR

In the early stages of planning the implementation and design of AR-SEE, we were faced with an important question: "How can a non-real-time, computationally demanding simulation be realized on a computationally limited mobile phone for AR?" Since our

literature search did not yield any sources that addressed this question, we derived a series of potential solutions ourselves. This section discusses our simulation integration decisions, potential alternatives, and the impact on the AR-SEE UI and visualizations. We hope that this discussion will help to inform other AR application developers or researchers about approaches to integrate computationally intense simulations with mobile AR.

3.6.1 Architectural Simulation Integration

We considered three different approaches: 1) Developing algorithms to approximate a continuous simulation on the phone in real time, 2) using distributed computing resources to perform the simulation remotely in real-time, but with network lag, and 3) pre-computing the simulation offline and using the resulting data at discrete points in a 24 hour span and with specific spatial layouts for the house, which is the approach that was taken. We took the 3rd approach because 1) it had minimal dependence on outside computing resources, which our end users (i.e. students) would not have access to 2) it worked within the minimal computational resources on the phone, which we knew would already be limited by AR already and 3) using the pre-computed values, the interactive AR application would have accurate data, which was desired for effective education. However, this choice did have an impact on the design of the user interface and visualization.

3.6.2 Impact on the AR-SEE UI and visualization

In AR-SEE, because the pre-computed simulation data are available only at discrete times of the simulated day and for specific layouts (i.e., you can only position the window in certain places), the interface and visualizations are also interactively limited: 1) *GUI*: using buttons rather than a slider on the 2D interface to enable interactive time change and 2) *TUI*: the implementation of the AR markers as toggle buttons. The 3D information of the window and roof markers was discarded because the simulation only had temperature information at specific points. In future work, it would be interesting to combine approaches, compare the use of discrete versus continuous simulations, investigate the effect these choices would have on the UI design, and the implications for education and learning.

4 PILOT STUDIES AND ITERATIONS

Two pilot studies with nine teachers and thirteen high school students were conducted to evaluate the usability and acceptability of AR-SEE. After each study, we refined and improved the AR-SEE prototype based on user feedback, resulting in two development iterations. The design, improvements made, and study results are presented here.

4.1 The First Pilot Study: Teachers

Nine local teachers participated with ages varying from 25 to 62 and teaching experience ranging from <1 year (student teaching as part of undergraduate degree) to 25 years. Participants progressed through the study one at a time. First experimenters gave a brief demonstration of the basic interface features. Next participants interacted with AR-SEE for approximately 10-30 minutes, during which they were often prompted to “think out loud”. Then they were interviewed and asked 15 specific questions about their experience with AR-SEE for 10-30 minutes. Participants were videotaped during the study.

4.1.1 The First Iteration

When this study was conducted, AR-SEE had two markers: one for a movable tree and another multi-target marker box for the house and the rest of the objects.

Participant Feedback: The overall opinion of the application was positive. While an early prototype, most of the testers did not find it difficult to navigate and use. Reactions varied from “I think it’s pretty good” to “This is awesome.” We found that participants had no issue using the interface once all the features have been explained—most of the testers believed they could easily use the software again on their own.

There were issues and complaints which drove our future development: The time controls in the GUI was difficult to understand (i.e., what time is it and what impact is it having on the scene); it was recommended that icons be added to the GUI in addition to the text, to give participants better feedback relating material names and images. Moreover, we found that the multi target box shaped markers did not track as well as the planar markers, likely due to human error in the creation of the markers. We found that due to the chosen viewing angles of users, planar markers provided better tracking results. Participants found the tree marker was even more error prone. Users were confused about being able to rotate the house with relative to the sun using a button, since they could also rotate the entire scene by manipulating the physical markers. Lastly, participants seemed interested in the technology, but some had trouble seeing the educational benefits of the one marker system. They were more receptive to the notion of the physical house interface.

4.2 Second Pilot Study: High school Students

Thirteen local high school students participated in the pilot study. Five of the students interacted with the AR-SEE multi marker version (see section 3) and 8 interacted with a single marker version. Besides this, the procedure was the same as the first pilot.

4.2.1 The Second Iteration

Summary of Changes Made: Many improvements were made from the previous pilot study: the GUI was made more intuitive and easier to understand by adding text to icons; the GUI layout was changed to make time control more intuitive and the house rotation option was removed. The main target marker was changed to a planar marker for better tracking. Also, we added additional tangible markers with a Lego house (see section 3).

Participant Feedback: The overall opinion of the application was positive. Many participants suggested having better graphics. Participants felt that the GUI option for seeing the internal features of the house was still ambiguous—some participants believed the components that were hidden were actually removed and saw different results than expected. For the third iteration, this prompted us to create a translucent ‘x-ray’ toggle for the house, as shown in section 3.

4.3 Lessons Learned from Participant Feedback

After two iterations, there were several lessons learned based on our observations and participant feedback in interviews.

The Effect of Phone Size on Visualization Understanding: One of the questions we asked users was whether the size of the phone would have an effect on the understanding of the simulation. To our surprise, all the participants said “no”. Some participants noted that a larger screen size might enable us to put in more detail but that it may not be necessary. While at the same time, several of the participants complained that the letters and numbers were too small. We suspect that the interactive camera control allowed them to get close enough to comprehend the visualization and also allowed them to move far enough away to get a more

global picture of the scene. This is supported by observing the participants interaction as well.

Combining 2D GUI and 3D Tangible Interfaces: Another of our initial concerns was the intuitiveness of the interface when using a combination of a 2D GUI and a 3D tangible interface. It confused users that they could rotate the entire world with the tangible interface but could only rotate the house relative to the sun using the 2D GUI. A potential lesson we can glean from this is that the interactions of the 2D GUI should be distinct from the interactions of the 3D tangible interface. That is, the affordances of tangible interfaces indicate that they should be mapped to 3D spatial interactions. Whereas, the affordances of 2D GUI buttons indicate that they should only affect non-spatial interactions, such as changing the material on the house.

An anomaly for this idea is using the 2D GUI to change the time of day, which also affects the sun's 3D spatial position. Several users were confused by this. In retrospect, had we made a tangible sun, users could have moved the sun to change the time. We do not know the best way of doing this and more objective studies are needed to understand this phenomenon. This suggests that intuitive ways to combine 2D GUIs and 3D tangibles in the same application should be considered in future research, especially when considering time and space.

5 USER STUDY: USABILITY AND LEARNING

The objective of this between-subjects study was to investigate the usability AR-SEE and its impact on learning about Passive Solar Energy (PSE). Three versions were compared: a Single Marker version that uses only touch screen interactions; a Multi Marker version (section 3) that uses a mix of tangible and touch screen interactions; and a Desktop PC version that uses a mouse.

5.1 Hypotheses

These hypotheses were devised based on 1) our observations in the pilot studies and 2) the literature in education on hands-on learning. Because MULTIMARKER AR integrates more hands-on learning practices than other conditions, we expected it to have significant learning and motivational benefits.

H1. Multi Marker AR will yield slower interaction times than Single Marker and Desktop

H2. There will be fewer interface errors for Multi Marker AR than Single Marker AR but more than Desktop

H3. Multi Marker AR will enable better memory for learning than Single Marker and desktop interfaces.

H4. Multi marker AR will yield higher motivation than Single Marker and Desktop

5.2 Conditions

There were three conditions compared in the between subjects study: 1) Desktop, 2) Single marker AR, and 3) Multimarker AR. Participant assignment to conditions was random. This section details the major differences between the three conditions.

5.2.1 Multi Marker AR (MULTIMARKER)

This condition used the AR-SEE prototype, as described and pictured in section 3. We used a HTC Desire HD smart phone with a 4.3 inch screen.

5.2.2 Single Marker AR (ONEMARKER)

All interface interactions are handled using the touch screen. The participants also have the option to look around the scene and zoom into the scene by changing or the phones' physical location. We used a HTC Desire HD smart phone with a 4.3 inch screen.



Figure 5. ONEMARKER condition

5.2.3 Desktop (DESKTOP)



Figure 6. DESKTOP condition

Users interacted with the same GUI as SINGLEMARKER using the mouse (figures 2 and 6). Participants held the right mouse button to rotate the virtual camera about the scene. They zoomed in and out using the mouse wheel. They interacted with the button interface using the left mouse button. Participants used a 22 inch LCD monitor.

5.3 Population

The population consisted of 36 students, 10, 11 and 12 completed the entire test per desktop, single marker and multi marker conditions respectively. The population consisted of both graduate and undergraduate computer science students from a user interfaces course with ages ranging from 20 to 30 years. The participants had none or very little knowledge of PSE or AR.

5.4 Procedure

The study took place over two 30 minute sessions, approximately 24 hours apart to test memory retention and learning.

Day 1:

1. *Pre-interview* - established participants' prior knowledge of PSE through a self-rated Likert scale. Demographic information (e.g., age) was also collected.
2. *Interface training* - This trained the participants on how to interact with the user interface and demonstrated all the functionality of the simulation.
3. *Directed Interaction* - This was the main usability testing phase of day 1. Participants were given verbal instructions to complete a series of simple 1 step tasks. A single instruction was given and then participants performed the task. There were 15 instructions in all. The task instructions did *not* include interface instructions (i.e., press a button to select the small windows). Rather, the instructions were the same for all three conditions simulation (i.e., change to the small windows).

Day 2:

1. Learning and Motivation questionnaires - participants answered PSE related questions with the intention of measuring memory retention, motivation for future learning, and learning effectiveness.
2. Optimization task - participants were asked to find the optimal configuration of the house. The simulation was locked to 12pm. Participants had to determine which configuration was most optimal for energy usage.
3. Post-interview - participants were asked to give their opinions on the software. This included a repeated measure of PSE knowledge with a self-rated 5-Likert scale.

5.5 Metrics

We employed numerous metrics to assess, usability, learning effectiveness, and motivation.

5.5.1 Usability

Directed Interaction Time - On the first day, the total amount of time that it took participants to complete the tasks was logged.

Directed Interaction Errors - During the directed interaction on the first day, if the participants made a mistake in following the directions, this was counted as an error. During the directed interaction, interactions with the interface were counted.

Optimal Configuration Time - During the optimization phase, we recorded the amount of time to find the optimal configuration.

Optimal Configuration Errors - For the optimization phase, the optimized configuration was determined before-hand—wide roof, brick base material, asphalt roof material and double small windows. Each one of these configurations options that the participants failed to select counted as an error.

5.5.2 Learning Effectiveness

Self-rated Knowledge of PSE - Likert scale of 1 to 5, 1 being minimal knowledge, 5 being very knowledgeable. This was asked before the intervention on the day 1 and after the optimization test on day 2.

Written questionnaire on PSE concepts - Graded on scale of 0-7, 7 being completely correct and 0 being completely incorrect. This questionnaire was created by our co-author who is an expert in science education and PSE. Given on the second day, this questionnaire consisted of seven questions about concepts of PSE (e.g., How does heat transfer from the sun interact with the materials of and in the house?). Each question was worth a point. The questionnaires were (blind) graded by the authors.

5.5.3 Motivation

We asked two 5-Likert scale questions (1 low motivation, 5 high motivation): that asked 1) rate your motivation to continue learning about passive solar energy and 2) rate your motivation to continue learning about passive solar energy using the application you used yesterday.

5.6 Results

5.6.1 Usability

Table 2. Mean Time (Seconds)

Interface	Directed Instruction	Optimal Configuration Test
DESKTOP	73.7	52.53
ONEMARKER	129.69	73.76
MULTIMARKER	177.77	85.99

Time (table 2): For the Directed Interaction, with a one-way ANOVA, we found a significant effect of interface on interaction time ($F(2,33) = 47.503, p < 0.001, \eta^2 = 0.746$). Tukey's Honest Significant Difference pairwise comparisons showed significant differences between DESKTOP and ONEMARKER ($p < 0.001$), between DESKTOP and MULTIMARKER ($p < 0.001$), and between ONEMARKER and MULTIMARKER ($p < 0.001$).

For the Optimal Configuration test, with a one-way ANOVA, we found a significant effect of interface on time ($F(2,31) = 5.999, p < 0.006, \eta^2 = 0.279$). Tukey's Honest Significant Difference pairwise comparisons showed significant differences between DESKTOP and MULTIMARKER ($p < 0.005$). Thus, $H1$ cannot be rejected.

Errors: One-way ANOVA showed no significant effects for interface on Optimal Configuration test errors ($F(2, 36) = 1.537, p = 0.270$), and no significant effects for interface on Directed Instruction errors ($F(2,36) = 1.646, p = 0.207$). Thus, $H2$ is rejected.

5.6.2 Learning Effectiveness

Table 3. Self-Rated Knowledge of PSE mean ranks

Interface	Day 1	Day 2
DESKTOP	1.18	3.00
ONEMARKER	1.91	3.45
MULTIMARKER	1.59	3.18

Self-rating (table 3): Although a Kruskal-Wallis test ($\chi^2(2) = .631, p = .730$) shows no significant effects of interface on the 5-Likert, 'Self-rated Knowledge of PSE,' we did find significant effects within all conditions between day 1 and day 2 on this metric. Wilcoxon Signed-Rank tests show significant differences in DESKTOP ($Z = -2.414, p < .016$), ONEMARKER ($Z = -2.774, p < .006$), and MULTIMARKER ($Z = -2.848, p < .004$). This suggests that the simulation we developed, which was the same in all three conditions, increased the user's self-perception of their level of PSE knowledge, regardless of interface.

Written questionnaire: A Kruskal-Wallis test showed no significant effects for interface on 'Written questionnaire on PSE concepts' ($\chi^2(2) = 2.379, p = .304$). Thus, $H3$ is rejected.

5.6.3 Motivation

For 5-Likert ratings of 'Motivation to Learn More about PSE,' DESKTOP, ONEMARKER, and MULTIMARKER, a Kruskal-Wallis test showed no significant effects for interface on motivation ($\chi^2(2) = 2.673, p = .263$). For 5-Likert ratings of 'Motivation to Learn More about PSE using this application,' DESKTOP, ONEMARKER, and MULTIMARKER, a Kruskal-Wallis test showed no significant effects for interface on motivation ($\chi^2(2) = .201, p = .905$). Thus, $H4$ is rejected.

5.7 Discussion

Time: the AR interfaces increased task completion time. Based on our observations of user behavior, MULTIMARKER yielded slower times because 1) users physically moved real objects rather than pushing buttons and 2) the marker-based toggle button interface required user to hold the phone in front of the physical markers until the recognition and tracking algorithms identified the marker. In the MULTIMARKER system, users tended to treat the physical environment separately from the visualization on the phone. This may be a downside of using mobile phone AR instead of a head mounted display approach.

Learning: MULTIMARKER did enable learning, but not significantly more than DESKTOP or ONEMARKER. In general, these results are surprising to us, since they are in contrast to the

majority of educational literature on passive solar energy education that indicate hands-on tasks (i.e. physically interacting with house) can improve learning and retention [3]. It is possible that the task was not complex enough to yield differences in learning. We expect that with a significantly more complex task (i.e., more house options and more simulated geographical environments) that we will see an effect on learning.

Motivation: there were no measurable differences for self-rated motivation for any of the interfaces. This is also in contrast to the literature [27], since we recruited participants with AR minimal experience. We suspect that this may be a disadvantage of using self-rated motivation rather than behavioral measures. Moreover, we expect that there would be clear differences if we had performed a similar study as a within subjects study so that users could directly compare the interfaces instead of experiencing only one interface. We aim to investigate this in the future.

6 CONCLUSION

In our formal study, although there were significant differences in task completion time, there was no clear winner for learning benefits or motivation among the desktop interface, a GUI-based mobile phone AR interface and GUI-is needed to determine the learning impact of AR on passive solar energy education.

However, we were pleased that our approach to integrating computationally intensive architectural simulation with an interactive simulation and visualization had a positive impact on learning, regardless of the interface used. Involving real end users (i.e. high schools students and teachers) in development was helpful to create an effective simulation and encouraged for the acceptability of mobile phone AR in the classroom.

In the future, we aim to further reinforce hands-on learning practice in AR-SEE with the use of additional sensors (i.e., an instrumented model house) to enable more efficient tangible interfaces for reconfiguring the real-time simulation. We also plan to integrate significantly more complex simulation datasets, house modification options, and simulated geographical locations. We expect that this increased task complexity will be more likely to demonstrate the learning effects of tangible AR on mobile phones. Then we will conduct further formal studies with both teachers and children in classroom settings to investigate AR-SEE's impact in both individual and collaborative learning environments.

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REFERENCES

[1] Quarles, J., P. Fishwick, S. Lamptang, I. Fischler, and B. Lok, A mixed reality approach for interactively blending dynamic models with corresponding physical phenomena. *ACM Transactions on Modeling and Computer Simulation (TOMACS)*, 2010. 20(4): p. 22.

[2] Kaufmann, H. and D. Schmalstieg, Mathematics and geometry education with collaborative augmented reality. *Computers & Graphics*, 2003. 27(3): p. 339-345.

[3] Vygotskij, L.S. and A. Kozulin, *Thought and language*. 1986: MIT press.

[4] Web page accessed May 26, 2011]; Available from: <http://designcoalition.org/kids/energyhouse/pdfpage.htm>.

[5] Rohs, M., Marker-based embodied interaction for handheld augmented reality games. *Journal of Virtual Reality and Broadcasting*, 2007. 4(5): p. 1860-2037.

[6] Schmalstieg, D. and D. Wagner. Experiences with handheld augmented reality. 2007: IEEE Computer Society.

[7] Henrysson, A., M. Billinghurst, and M. Ollila. Virtual object manipulation using a mobile phone. 2005: ACM.

[8] Chen, Y.C. A study of comparing the use of augmented reality and physical models in chemistry education. 2006: ACM.

[9] Fjeld, M., J. Fredriksson, M. Ejdestig, F. Duca, K. Bötschi, B. Voegtli, and P. Juchli. Tangible user interface for chemistry education: comparative evaluation and re-design. 2007: ACM.

[10] Kaufmann, H. and A. Dünser, Summary of usability evaluations of an educational augmented reality application. *Virtual Reality*, 2007: p. 660-669.

[11] Shelton, B.E. and N.R. Hedley. Using augmented reality for teaching earth-sun relationships to undergraduate geography students. 2002: IEEE.

[12] Nischelwitzer, A., F.J. Lenz, G. Searle, and A. Holzinger, Some aspects of the development of low-cost augmented reality learning environments as examples for future interfaces in technology enhanced learning. *Universal Access in Human-Computer Interaction. Applications and Services*, 2007: p. 728-737.

[13] O'Malley, C. and S. Fraser, Literature review in learning with tangible technologies. 2004.

[14] Webster, A., S. Feiner, B. MacIntyre, W. Massie, and T. Krueger. Augmented reality in architectural construction, inspection and renovation. 1996: Citeseer.

[15] Behzadan, A.H. and V.R. Kamat. Enabling smooth and scalable dynamic 3d visualization of discrete-event construction simulations in outdoor augmented reality. 2007: IEEE Press.

[16] Wang, X. and M.A. Schnabel, *Mixed Reality in Architecture, Design, and Construction*. 2008: Springer-Verlag New York Inc.

[17] Zhou, F., H.B.L. Duh, and M. Billinghurst, Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. 2008.

[18] Looser, J., M. Billinghurst, and A. Cockburn. Through the looking glass: the use of lenses as an interface tool for Augmented Reality interfaces. 2004: ACM.

[19] Silva, R., P.S. Rodrigues, J.C. Oliveira, and G. Giraldi. Augmented Reality for Scientific Visualization: Bringing Datasets inside the Real World. 2004: Citeseer.

[20] Bane, R. and T. Hollerer. Interactive tools for virtual x-ray vision in mobile augmented reality. 2004: IEEE Computer Society.

[21] Slay, H., M. Phillips, R. Vernik, and B. Thomas. Interaction modes for augmented reality visualization. 2001: Australian Computer Society, Inc.

[22] Hedley, N.R., M. Billinghurst, L. Postner, R. May, and H. Kato, Explorations in the use of augmented reality for geographic visualization. *Presence: Teleoperators & Virtual Environments*, 2002. 11(2): p. 119-133.

[23] Liarakapis, F., I. Greatbatch, D. Mountain, A. Gunesh, V. Brujic-Okretic, and J. Raper, Mobile augmented reality techniques for geovisualisation. 2005.

[24] Furmanski, C., R. Azuma, and M. Daily. Augmented-reality visualizations guided by cognition: Perceptual heuristics for combining visible and obscured information. 2002: IEEE.

[25] White, S. and S. Feiner. SiteLens: situated visualization techniques for urban site visits. 2009: ACM.

[26] IES VE-Pro Software. May 26, 2011]; Available from: <http://www.iesve.com/software/ve-pro>.

[27] Cheng, L.K., C.S. Der, M.S. Sidhu, and R. Omar, GUI vs. TUI: Engagement for Children with No Prior Computing Experience. *electronic Journal of Computer Science and Information Technology*, 2011. 3(1).



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