Bringing science simulations/games to science classrooms: the pedagogy and orchestration issues

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Simulation & Science learning

- Simulate a model of a system or a process
- Visualize some invisible features of science phenomena
- Help students experience scientific discovery process
Simulation & Science learning

- Modeling-based learning
  - Students use appropriate representation to capture important features of a science phenomenon (Sengupta & Clark, 2016).
  - Students “use, create, share, and evaluate models to explain scientific phenomena (Shen, Lei, Chang, & Namdar, 2014).”
Simulation & Science learning

Jeremy Roschelle, 1992

FIGURE 1 The Envisioning Machine (labels added).
**Simulation & Science learning**

- Problem-solving game
  - Students learn through solving a challenging task in a simulation

```c
begin
int count=0;
while(true)
{
    if(TrainPassMe()){
        count++;
        print (count);
    }
    if(count==3){
        train0.Break(30);
        print(Train0 Break[30]);
        print("Train is stopping");
    }
}
```

The program governs the behavior of the track in (3)
Simulation & Science learning

• Problem-solving game
  – Students learn through solving a challenging task in a simulation

Tan & Biswas, 2007
Simulation & Science learning

- PhET (https://phet.colorado.edu/)
  - 150+ high quality simulations for physics, biology, chemistry, earth science...
  - Flash-based, now transferring to HTML5
Simulation & Science Learning

- Molecular Workbench (http://mw.concord.org/)
  - Java-based simulations for physics, chemistry, biology...
  - Now transferring to HTML5
  - Simulation development tool
  - Activity development tool
Simulation & Science learning

- Go-Lab (https://www.golabz.eu/labs)
  - An EU exchange platform for simulations.
  - Welcome all contributions from different countries
  - Activity development tool
Simulation & Science learning

- EJS (Easy Java Simulation)
  - EJSS (Easy JavaScript Simulation) (http://fem.um.es/Ejs/)
    - Application to build science simulations
      (by Prof. Francisco Esquembre)
Simulation & Science Learning

- **Virtual Physics Lab** Since 1996
  - By Prof. **Fu-Kwun Hwang**
  - Hundreds of science simulations built with EJS
  - Collected by MERLOT, National Science Teacher Association, etc.
  - Java-based simulations

HTML5
New Simulation Platform
Launch a new project in 2011
Launch a new project in 2011

Fu-Kwun Hwang

Francisco Esquembre

Chen-Chung Liu
New features

- Collaboration
- Pedagogical design
- Learning analytics
Collaboration
Pedagogical design

1) Select a specific simulation
2) Design a series of learning tasks
3) Provide prompt questions in each task
Learning analytics

Activity pattern (LSA)

Activity statistics by groups

Member contribution in a group
CoSci

100+ Simulations
A platform supporting scientists, teachers, and students to develop and apply computer simulations for the learning of physics.

https://CoSci.TW/
100+ Simulations
100+ Simulations

Buoyancy

Pressure
100+ Simulations

Velocity & Acceleration

Friction
100+ Simulations

Free falling / Projectile
100+ Simulations

Circular motion

Momentum and Energy
100+ Simulations

Collision
100+ Simulations

Harmonic motion

Thermodynamics
100+ Simulations

Waves

Optics
100+ Simulations

Electromagnetic
Pedagogical Design
Pedagogical design

• Simply providing simulations does not guarantee positive learning effect
  – Students do not know how to interact with simulations (Holzinger, Kickmeier-Rust, Wassertheurer, and Hessinger, 2009).
  – Interact with simulations on a superficial and playful level (Mayer, 2004; Swaak & de Jong, 2001)

➤ Students need different levels of supports in using simulations.
Leveraging multiple resources and extrinsic constraints including time, curriculum relevance, discipline constraints, and assessment constraints.

(From The special issue in Computers & Education 2013 by Pierre Dillenbourg)
Pedagogies using simulations

• Modeling-based learning with games
• Guided inquiry with simulations
• Critique on the inquiry with simulations
• Light-weight inquiry in classrooms
Modeling-based learning with games
Problem-solving simulation game

*Momentum + Collision*

High school students constructed the model of collision of two objects.
SMIC, 2020

Csci mini game 公司近聖誕出了一個物理小遊戲，小區覺得很有挑戰性，遊戲設定如下：

住在180公尺高的山壁上有一隻質量為 Mål(公斤) 的鬼魂，
以等速度 Vxa(公尺/秒) 向右(向X方向)飛移。在山坡上有一
顆質量為 Mbl(公斤) 南瓜。當鬼魂飛撞到南瓜時，鬼魂
黏在南瓜上，兩者一起滑落至山壁下（重力加速重 g=10
公尺/秒^2）。兩物掉落過程中不受任何外力，假設地面無摩擦力。
請你設計適當參數值(Vxa, Ma, Mb) 使得南瓜落地時恰
好擊中南瓜。

可調參數：
Vxa: 鬼魂速度 (公尺/秒)
Ma: 鬼魂質量 (公斤)
Mb: 南瓜質量 (公斤)
Problem-solving simulation game

- Pedagogical design
  - **Play:** student understand the goal of the game.
  - **Simulation:** students operate simplified simulation displaying how the velocities of two objects change after collision.
Problem-solving simulation game

- **Pedagogical design**
  - **Play**: student understand the goal of the game.
  - **Simulation**: students operate simplified simulation displaying how the velocities of two objects change after collision.
Problem-solving simulation game

- Model construction: students obtain a quantitative model of collisions to precisely solve the problem given by the game.
Problem-solving simulation game

- **Test model**: Students use the model they built to solve the game. To avoid trial-and-error they were only allowed to play the game three times.

- **Writing report**: Students write a report regarding the task they achieved in that session.
The experiment and analysis

• To understand how 25 high school students build their own model in the inquiry activity.

• The modeling-based learning activity was implemented in a 90-minute session.
  – Initial and final models
Model change
Guided inquiry activity with simulations
Scientific literacy

• Scientific literacy has been emphasized in science education standards globally (e.g., NGSS Lead States, 2013).

• The ability to “do science” (OECD, 2016).
  – to explain phenomena scientifically
  – to design scientific inquiry
  – to interpret data scientifically
Cookbook style laboratory instruction

The cookbook-style laboratory instruction has unfavorable effect on science learning.

(Blanchard et al., 2010; Scalise et al., 2011).
In one class period, the teacher instructed the students how to use the CoSci simulation and demonstrated how to conduct virtual experiments using the simulation.

Then the students were allowed to conduct their own inquiry with the simulation for two class periods.

The students’ inquiry was guided by the system through provided inquiry questions and prompting hints and questions.
Guided inquiry with simulations

Buoyancy + Scientific literacy

Middle school students investigate why objects sink or float in the liquid and the phenomenon of buoyancy.
Students configured their own inquiry plan.
Guided inquiry with simulations

- A comparative study
  - One class was taught by the teacher
  - The other learned by the guided inquiry
- Both classes participated in a 100-minute learning session.
- Data set
  - School science test scores
  - Scientific literacy test scores
Scientific literacy test

OECD Scientific literacy framework

- Explaining phenomena scientifically (SC-A)
- Design of scientific inquiry (SC-B)
- Interpretation of the data (SC-C)

<table>
<thead>
<tr>
<th>Step</th>
<th>Rock Volume $cm^3$</th>
<th>Mass in Air $g$</th>
<th>Mass in Water $g$</th>
<th>Weight in Air $g$</th>
<th>Weight in Water $g$</th>
<th>Mass in Water $g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>1200</td>
<td>1200</td>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Step 2</td>
<td>600</td>
<td>600</td>
<td>900</td>
<td>600</td>
<td>900</td>
<td>600</td>
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<tr>
<td>Step 3</td>
<td>1200</td>
<td>0</td>
<td>300</td>
<td>1200</td>
<td>300</td>
<td>1200</td>
</tr>
</tbody>
</table>

1-1 請觀察步驟一到三的數據，你發現浮力的大小與哪些數值相同？為何如此？

1-2 請觀察步驟一到三的數據，解釋石塊在水中的重量如何變化？為何如此？
# Scientific literacy test

Table 5. Means and standard deviations of the posttest, delayed-test, and post achievement scores

<table>
<thead>
<tr>
<th></th>
<th>Scientific Literacy Posttest</th>
<th>Scientific Literacy Delayed-test</th>
<th>Post School Science Achievement Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>S.D.</td>
<td>M</td>
</tr>
<tr>
<td>The treatment group</td>
<td>14.92</td>
<td>6.23</td>
<td>19.08</td>
</tr>
<tr>
<td>The control group</td>
<td>13.73</td>
<td>5.94</td>
<td>14.44</td>
</tr>
<tr>
<td>Independent sample t tests</td>
<td>$t=0.689, p=.494$</td>
<td></td>
<td>$t=2.522, p=.015$</td>
</tr>
</tbody>
</table>
better long-term learning effect on scientific literacy

Predicted learning curve by Horton (2001)

Modeling-based approach

Traditional teaching

SMIC, 2020
Critique on the inquiry with simulations
Critique on the inquiry with simulations

• The practice of critiquing helps students develop integrated understanding of science concepts (Chang & Chang, 2013; Chang & Linn, 2013).

• Critiquing helped students improve their scientific explanations (Matuk et al., 2019).
The Student Critique Design

- Student complete the critique worksheets.
- The teacher led the whole class discussions of the critiques.
- Inquiry with the simulation
According to the results above, Hsian-Hsian claims that “I hypothesized that the buoyant force equal to the weight of the fluid displaced by the object. The experiment results support my hypothesis. So, I will not change my hypothesis. This is because the weight of the fluid displaced by the object is equal to the volume of the object under the fluid. The volume of the object under the fluid is equal to the buoyant force received by the object. So the weight of the fluid displaced by the object is equal to the volume of the object under the fluid.” Is this claim reasonable, if not, how do you revise the claim?

**Student Critique Worksheets**

---

<table>
<thead>
<tr>
<th>Exp1</th>
<th>rhoS</th>
<th>M</th>
<th>V</th>
<th>rhoA</th>
<th>Vu</th>
<th>Vs</th>
<th>scale1</th>
<th>scale2</th>
<th>scale3</th>
<th>Buoyant F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.00</td>
<td>600.00</td>
<td>1000.00</td>
<td>0.60</td>
<td>600.00</td>
<td>600.00</td>
<td>0.00</td>
<td>600.00</td>
<td>0.00</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>800.00</td>
<td>1000.00</td>
<td>0.80</td>
<td>800.00</td>
<td>800.00</td>
<td>0.00</td>
<td>800.00</td>
<td>0.00</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>1000.00</td>
<td>1000.00</td>
<td>1.00</td>
<td>1000.00</td>
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<tr>
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<td>1000</td>
</tr>
<tr>
<td></td>
<td>1.40</td>
<td>1400.00</td>
<td>1400.00</td>
<td>1.00</td>
<td>1000.00</td>
<td>1000.00</td>
<td>0.00</td>
<td>1400.00</td>
<td>0.00</td>
<td>1400</td>
</tr>
</tbody>
</table>
Students took part in the inquiry with the simulation and inquiry map.
The experiment and analysis

• A comparative study
  – Traditional group
  – Teacher demonstration group
  – Student critique group

• All classes participated in a 100-minute learning session.

• Data set
  – Scientific literacy test scores
Conventional No-Simulation Teaching

The traditional lecture treatment also involved three class periods but teaching through textbook-based lectures with no simulation.

It involved teacher lectures about the concepts, and student practice on assessment items relating to sinking and floating.
In one class period, the teacher instructed the students how to use the CoSci simulation and demonstrated how to conduct virtual experiments using the simulation.

Then the students were allowed to conduct their own inquiry with the simulation for two class periods.

The students’ inquiry was guided by the system through provided inquiry questions and prompting hints and questions.
The students worked on worksheets prepared by the science teachers that asked the students to critique fictitious experiments with the CoSci sinking and floating simulation.

The teacher also led whole class discussions to engage the students in discussing their critiques.

Then the students were allowed to conduct their own inquiry with the simulation for two class periods. The students’ inquiry was guided by the system through provided inquiry questions and prompting hints and questions.
Results

• The ANCOVA result indicates that there is a significant treatment effect ($F=7.908$, $p=0.001$).

• Paired comparisons with a modified Bonferroni correction reveal significant differences between the Student Critique treatment and the traditional teaching treatment, but no significant difference between any two of the others.
The critique approach showed medium effect size over the traditional approach.
Reflections

• The three designs improved science learning effect.

• However, the three designs assume the high readiness of technology use in schools
  – Modeling-based learning with games
  – Guided inquiry with simulations
  – Critique on the inquiry with simulations
Light-weight inquiry in classrooms
Light-weight inquiry with computer simulations

**Buoyancy + Scientific literacy**

Middle school students investigate why objects sink or float in the liquid and the phenomenon of buoyancy.
Classroom orchestration

- Minimalism principle: only 5 iPads and a projector were used
- Teacher-led collaboration: teacher guided students through worksheets
- Students went through the inquiry steps to build the science knowledge of buoyancy.
- They shared their group conclusion on the white board.
The experiment and analysis

• A comparative study
  – 24 in the Light-weight inquiry group
  – 25 in traditional teaching approach
• Both groups learned Buoyancy in 4 45-minute sessions
• Data collection
  – Pre- and post-test for the scientific literacy
  – Pre- and post-test for the science knowledge
Science knowledge

Table 1. The repeated measure analysis (ANOVA) of the science knowledge

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Pre-test</th>
<th></th>
<th>Post-test</th>
<th></th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>24</td>
<td>3.79</td>
<td>1.64</td>
<td>6.21</td>
<td>2.34</td>
<td>2.58</td>
<td>.115</td>
</tr>
<tr>
<td>Light-weight</td>
<td>25</td>
<td>3.36</td>
<td>1.44</td>
<td>5.44</td>
<td>1.66</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The two groups did not show significant difference in their science knowledge.
Scientific Literacy

<table>
<thead>
<tr>
<th>Scientific Literacy</th>
<th>Group</th>
<th>N</th>
<th>Adjusted Mean</th>
<th>Std. err.</th>
<th>$F$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>Trad.</td>
<td>24</td>
<td>1.47</td>
<td>.14</td>
<td>2.38</td>
<td>.13</td>
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<tr>
<td></td>
<td>Ligh-W.</td>
<td>25</td>
<td>1.85</td>
<td>.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC-A</td>
<td>Trad.</td>
<td>24</td>
<td>.63</td>
<td>.07</td>
<td>1.29</td>
<td>.26</td>
</tr>
<tr>
<td></td>
<td>Ligh-W.</td>
<td>25</td>
<td>.55</td>
<td>.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC-B</td>
<td>Trad.</td>
<td>24</td>
<td>.45</td>
<td>.06</td>
<td>.10</td>
<td>.76</td>
</tr>
<tr>
<td></td>
<td>Ligh-W.</td>
<td>25</td>
<td>.44</td>
<td>.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC-C</td>
<td>Trad.</td>
<td>24</td>
<td>.64</td>
<td>.05</td>
<td>7.34**</td>
<td>&lt;.01</td>
</tr>
<tr>
<td></td>
<td>Ligh-W.</td>
<td>25</td>
<td>.74</td>
<td>.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $p<.05$; ** $p<.01$

Explaining phenomena scientifically (SC-A)
Design of scientific enquiry (SC-B)
Interpretation of the data (SC-C)

The light-weight inquiry approach is helpful for improving students’ ability in interpreting data.
Dream-based research vs. Practice-driven innovation research

- Dream-based research
  - telling teachers a dream
  - rather than practically helping them transform teaching/learning
Dream-based research vs. Practice-driven innovation research

- Practice-driven innovation research
  - Create innovations practically transforming teaching/learning in the context
  - Working with schools and teachers
  - Address teachers’ orchestration requirements
  - Demonstrate practical impacts
Dream-based research vs. Practice-driven innovation research

• CoSci platform
  – 100+ simulations
  – Learning activity design

• Being collaborating with 8 schools in Taiwan to bring these simulations to schools
Dream-based research vs. Practice–driven innovation research

- The four simple and feasible pedagogical designs were tested in schools
  - Guiding students in model-based learning
  - Developing scientific literacy
We hope:

The tool, content, and pedagogical method we create can practically improve the teaching and learning in schools.
Collaboration Network

Spain
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References

