Multisensory Learning In Adaptive Interactive Systems

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Who I am

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MSc Cognitive Science

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Research Fellowship
From cognition to technology

- multisensory perception and performing arts may have a role in enhancing learning.
- neuroscience research highlights the role of specific sensory modalities and their integration in learning specific tasks, especially in developmental years.
- technology does not integrate this knowledge in its design.
Multisensory learning

The synergy, or interaction, between the senses and the fusion of their information content is called "multisensory integration" (Meredith, 2002).

Multisensory perceptual learning and cross-modal generalization has been reported, where stimuli share some common characteristics (Bartolo and Merchant, 2009).

The salient characteristics for a given task are more likely to be generalized across modalities (Jain et al., 2010).

Multisensory processing and information

The synergy, or interaction, between the senses and the fusion of their information content is called "multisensory integration" (Meredith, 2002).
Superior colliculus neurons are multisensory, i.e. they respond to stimuli coming from more than one sensory mode.

Research Questions

A. Does users’ non-verbal behaviors be relevant in learning?

B. What cognitive states effectively support learning, both in children and adult? Can we automatically detect them?

C. Which sensory modalities enhance embodied understanding and proprioceptive feedback in full-body learning tasks?

D. How multisensory technology should be designed to properly enhance learning outcomes? How do we evaluate its efficacy?
Computational model: adaptive multimodal system
Adaptive multimodal system

e.g.: Movement and gesture analysis
Adaptive multimodal system

INPUT

- Physical signals
- Low-level features
- Mid-level features
- Concepts and structures

Sensors
Adaptive multimodal system

- Concepts and structures
- Mid-level features
- Low-level features
- Physical signals

INPUT

Output:
- Energy
- Contractions
- Symmetry
...
Adaptive multimodal system

INPUT

- Physical signals
- Low-level features
- Mid-level features
- Concepts and structures

Segmenation

Fluidity

Lightness
Adaptive multimodal system

- Physical signals
- Low-level features
- Mid-level features
- Concepts and structures

Emotions
- Cognitive
- Expressive
- Behaviors
Analysis of motoric, affective and social interaction of user/s

System architecture

Session data management

User interface

Analysis of motoric, affective and social interaction of user/s

Low level features

Sensors (e.g. Kinect, VR, MYO, microphone, Motion capture, ...)

Sonification - Audio Feedback

Visualization
Feedback model
Two EU-ICT Projects as Case Studies

weDRAW  TELMI

Different solutions for different targets
Why weDRAW and TELMI?

Music playing is a multisensory, embodied and social activity by its definition (Dalcroze, 1930).

Developmental studies point out the close relationship between bodily movement and musical sounds (Stern, 1985; Papousek, 1996).
A novel approach to design unique serious game environment that suits both for typically develop children and for sensory impaired ones (e.g. visual impaired and dyslexic children)
Methodology

Identification of the most suitable sensory modality for perceiving and learning the arithmetic and geometry concepts pedagogues identified.

Psychophysical input

Metrical and performance indicators are identified in order to assess whether the project reached its pedagogic, scientific, and technological objectives.

Evaluation

Identification of the arithmetic and geometric concepts to be learned at different ages and levels.

Psychophysical input

Identification of the most suitable sensory modality for perceiving and learning the arithmetic and geometry concepts pedagogues identified.

Technology development

Two major pillars: (i) user-centric iterative participatory design and (ii) early and fast prototyping.

Evaluation

Highly multidisciplinary with an integrated approach
Pedagogical consideration

- Define math concepts to work on, considering teachers' experience
- Identify specific difficulties in learning math for visually impaired children
- Initial design ideas
- Mapping of UK and Italia national curriculum math teaching
Which sensory modalities for which concepts

- Number line: The influence of sound pitch on length perception
- Fraction: Fractions with the body: upper-low body part relation
- Shapes and isometric transformation: Pitch and size and triangle completion task: audio-visual crossmodal interaction
- Angles: Angles and pitch aperture: audio-visual crossmodal interaction

Shapes and isometric transformation

Number line

Fraction
Based on psychophysics association between pitch and shape, well studied in synesthesia literature (Rigas and Alty, 2005), (Lawrence, 1975), (Mondloch, Maurer, 2004)
Double model, suitable both from younger and/or blind children (the narrative one) and from older ones (the music map one)
Cartesian Garden sonification model

- The second continuous sound is playing as long as the controller stays within the bounds of any green rectangle.
- The first continuous sound is playing as long as the controller stays within the bounds of any blue rectangle.
- When the player reaches a “new magnitude” he hears a bell ringing.
- The sound stops playing because the user leaves the virtual corridor boundary.

Virtual corridor system
AngleShapes Game Low-vision adaptation

video

CartesianGarden: sonification model for visually impaired children

video
What cognitive states should we monitor in learning tasks?

How non-verbal communication can be used in automatic affective detection?

What cognitive states literature highlight to be important in learning tasks?

What guidelines for affective computing we can use to develop adaptive educational serious-games?

How HCI research literature efficiently address its design to sensory impaired learners?
Reflective thinking

is integral to learning (Kolb, 2015), (Mezirow, 1991), (Rodgers, 2002), (Dewey 1933) and may be necessary for mathematical problem solving (Navarro, Aguilar, Alcalde, & Howell, 1999).

Engagement

It is something strictly related to motivation and has a great power on participation and positive outcomes in learning (Fredricks, Blumenfeld & Paris, 2004).

Confidence

Its importance in learning has been proven and linked with the amount of effort and the level of persistence that a learner will put into the completion of the learning task in the face of barriers (A. Bandura, 1977).
We identified different sensors-based and motion-based features, but for the use in our full-body platform we found measurements of precision of movements and trajectories, velocity, hesitance, number of trials, face gaze, body posture, energy of movements as the most representative.
To which extent visual impairment may affect the development of nonverbal communication patterns in visually impaired children?

We performed a double check annotation of video segments, looking for engagement, self-confidence and what non-verbal cues were used to recognize those states.
Preliminary results show that cues as gaze still have a relevant weigh in considering engagement and self-confidence.

Some annotated behaviours are *continuous*, that can be present in both the states, co-occurring with other cues.

While other features are binary behaviors.

<table>
<thead>
<tr>
<th>Id</th>
<th>Cues</th>
<th>%</th>
<th>Id</th>
<th>Cues</th>
<th>%</th>
<th>Id</th>
<th>Cues</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Focused, direct movement</td>
<td>34.44</td>
<td>10</td>
<td>Gaze down</td>
<td>38.99</td>
<td>21</td>
<td>Exp. of positive emotions (e.g. laughter)</td>
<td>18.33</td>
</tr>
<tr>
<td>2</td>
<td>Jerky movement</td>
<td>25.00</td>
<td>11</td>
<td>Tendency to act</td>
<td>25.00</td>
<td>22</td>
<td>Nervous smile or laughter</td>
<td>13.99</td>
</tr>
<tr>
<td>3</td>
<td>Hesitating movement</td>
<td>22.78</td>
<td>12</td>
<td>Listening predisposition</td>
<td>25.00</td>
<td>12</td>
<td>Open mouth</td>
<td>10.00</td>
</tr>
<tr>
<td>4</td>
<td>Fluid movement</td>
<td>21.11</td>
<td>13</td>
<td>Body as a reference point</td>
<td>20.00</td>
<td>21</td>
<td>Nodding during tasks resolution</td>
<td>7.88</td>
</tr>
<tr>
<td>5</td>
<td>Impulsive movement</td>
<td>20.00</td>
<td>14</td>
<td>Gaze contact with the interlocutor</td>
<td>18.33</td>
<td>25</td>
<td>Grabbing clothes</td>
<td>7.88</td>
</tr>
<tr>
<td>6</td>
<td>Inhibited movement</td>
<td>17.22</td>
<td>15</td>
<td>Withdraw from action</td>
<td>16.77</td>
<td>26</td>
<td>Rocking</td>
<td>7.88</td>
</tr>
<tr>
<td>7</td>
<td>Not goal-oriented movement</td>
<td>16.77</td>
<td>16</td>
<td>Outward-facing gaze</td>
<td>13.99</td>
<td>27</td>
<td>Lips biting</td>
<td>6.77</td>
</tr>
<tr>
<td>8</td>
<td>Slow movement</td>
<td>15.00</td>
<td>17</td>
<td>A loss of posture alignment</td>
<td>13.33</td>
<td>28</td>
<td>Deictic gestures</td>
<td>5.00</td>
</tr>
<tr>
<td>9</td>
<td>Misalignment</td>
<td>18</td>
<td>18</td>
<td>A loss of balance (feet support instability)</td>
<td>13.32</td>
<td>30</td>
<td>Hands kept together</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>of different body planes</td>
<td></td>
<td>19</td>
<td>Posture openness</td>
<td>8.89</td>
<td>31</td>
<td>Hands hold behind back</td>
<td>4.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Touching face or mouth</td>
<td>0</td>
</tr>
</tbody>
</table>
Usability evaluation

How to evaluate the efficacy of multimodal learning games, considering both typical and sensory impaired children?
A new evaluation checklist

Basing our work on CLUE checklist (Ticianne, D. et al., 2018), we developed a new evaluation protocol, intended to be used by external observers during user interaction, that suits full-body multisensory serious-game for both typical and sensory impaired users.

https://tinyurl.com/sxof6mf
AngleShapes Game Usability

Typically developed children

N=111, age mean=8.66
AngleShapes Game Usability

V.I. children  N=3  age mean=10
Dyslexia screening and training

The SynchroHorse Race

An Android app to enhance temporal and rhythmic perception processing for dyslexic primary school children.
A new pedagogy model, based on enhancing *embodied* understanding and *proprioceptive feedback* of violin students.
My research on TELMI

Understanding motor-related features effectively involved in learning and practice music.

Multimodal archive of violin performances

Analysis of movement features for bowing control and automated teacher/student classification

Real-time feedback interface

User evaluation
Multimodal TELMI Archive

4 RCM violin performance

1 Teacher

3 Students

41 (21) Exercises

Traditional music education is mostly based on a master-apprentice relationship, with a long period of self-study for the students.

Traditional teaching methods of the biomechanics components of musical performance may be based on subjective perception.

Musical performance shares many characteristics, including health risks, in common with other skill-oriented activities, as sports.
Bowing techniques

Students’ performance and safety

A preliminary study

Body features analysis…

- Shoulders’ dynamics
- Shoulders’ position
- Upper body dynamics
... and human evaluation

01 Expert evaluation

We asked to three experts musicians to evaluate violin skills, through a questionnaire, using an interactive slider.

02 Internal consistency

Internal consistency was assessed through Cronbach’s.
Next step

We planned to extend the analysis to audio features, e.g. timbre, pitch and tonality.

The analysis of both motion and audio features for muscular tension is ongoing.
With the RCM of London, we performed a series of iterative design meetings to understand what kind of visual information can efficiently improved proprioceptive and embodied posture understanding while playing.

The final platform, SkyMotion, was evaluated by 8 violinists, through a series of semi-structured interviews.
### SkyMotion Evaluation

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Exp.1</th>
<th>Exp.2</th>
<th>Exp.3</th>
<th>Exp.4</th>
<th>Exp.5</th>
<th>Exp.6</th>
<th>Exp.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>… help you learn more quickly?</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>… improve your performance?</td>
<td>7</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>… increase your productivity?</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>… increase the effectiveness of your practice?</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>… make practicing easier?</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

**To what degree was this feedback...**

| 6   | … useful?                                                                | 7     | 6     | 7     | 6     | 4     | 4     | 7     |
| 7   | … easy to learn to operate?                                              | 7     | 5     | 5     | 5     | 6     | 6     | 7     |
| 8   | … something that did what you wanted it to do?                           | 7     | 4     | 6     | 5     | 4     | 3     | 7     |
| 9   | … clear and understandable?                                              | 7     | 5     | 6     | 5     | 6     | 4     | 7     |
| 10  | … flexible?                                                              | 6     | 5     | 5     | 6     | 2     | 5     | 6     |
| 11  | … easy to become skilled at?                                             | 7     | 5     | 7     | 5     | 5     | 6     | 7     |
| 12  | … easy to use?                                                           | 7     | 4     | 6     | 5     | 6     | 6     | 7     |
| 13  | … accurate?                                                              | 6     | 5     | 7     | 6     | 2     | 1     | 6     |
| 14  | … something you would use again?                                         | 7     | 6     | 7     | 6     | 5     | 2     | 7     |
| 15  | … something you would recommend to others?                               | 7     | 6     | 7     | 6     | 5     | 3     | 7     |

### Quotes

- "I would like to use SkyMotion with my students to help them understand the importance of working on own body before working on music performance."

- "It can be very useful for students at home, since after hours of practice they are tired and easily lose their correct posture and its naturalness, increasing muscular tensions."
THANK YOU

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https://www.researchgate.net/profile/Erica_Volta