Tangible User Interface for Chemistry Education: Comparative Evaluation and Re-Design

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ABSTRACT
Augmented Chemistry (AC) is an application that utilizes a tangible user interface (TUI) for organic chemistry education. The empirical evaluation described in this paper compares learning effectiveness and user acceptance of AC versus the more traditional ball-and-stick model (BSM). Learning effectiveness results were almost the same for both learning environments. User preference and rankings, using NASA-TLX and SUMI, showed more differences and it was therefore decided to focus mainly on improving these aspects in a re-design of the AC system. For enhanced interaction, keyboard-free system configuration, and internal/external database (DB) access, a graphical user interface (GUI) has been incorporated into the TUI. Three-dimensional (3D) rendering has also been improved using shadows and related effects, thereby enhancing depth perception. The re-designed AC system was then compared to the old system by means of a small qualitative user study. This user study showed an improvement in subjective opinions about the system's ease of use and ease of learning.

Author Keywords
Augmented Reality, Tangible User Interface, Comparison, Evaluation, Education, Organic Chemistry, Octet Rule

ACM Classification Keywords
Interaction styles, User issues, Virtual reality

INTRODUCTION
Augmented Chemistry (AC) is an application using a tangible user interface (TUI) to assist organic chemistry education [3] that was developed at HyperWerk FHBB [3][10]. It was extended with additional functionality and evaluated in a joint project which involved ETH, HyperWerk FHBB, and the aprentas school of chemistry [1]. In an empirical evaluation of AC, we studied how it compares to the traditional ball-and-stick model (BSM) of learning organic chemistry. Related work was later carried out by Chen [2]. This paper offers a section describing the AC system, followed by evaluation, system re-design, and a discussion and outlook section.

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SYSTEM DESCRIPTION
AC uses a TUI enabling users to compose and directly interact with 3D molecular models (Fig. 1, top). The system was designed to assist in teaching abstract organic chemistry concepts such as molecular forms, the octet rule, and bonding. Employing a widely used library called AR Toolkit [6], physical tools carry one or more fiducial markers, connecting each tool to a 3D model so that both the tool and the model can be seen in a composite image.

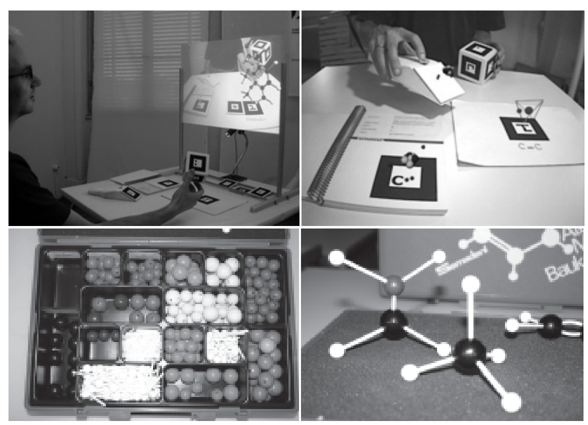

Figure 1: AC system, here with back-projection screen (top left). The rotation cube is operated with the right hand while the constructed molecule sits on the centre platform (mirror view, top right). The ball-and-stick model (BSM) served for comparison (bottom).

The system consists of a booklet, a gripper[1], a cube, a platform, a camera, and software. The booklet contains one element of the Periodic Table per page each with its name and relevant information. By using the gripper, users can pick up elements from the booklet and add them to the molecule in construction on the platform. By rotating the cube, the user rotates the molecule, which determines how and where the

[1] The gripper first consisted of a wireless mouse rebuilt into a cage with a marker. Now, the marker is simply fastened to a conventional wireless mouse.

new element shall bond. The function cards represent specialized functions which are activated when dragged onto the platform [3]. While optical tracking systems enabling smaller markers and function cards do exist and would free up tabletop real estate (e.g. ARTag), their source is not yet open. At the same time, we did not consider utilizing more cards for system configuration and internal/external DB access because of limited hardware real estate. Consequently, the limited physical space triggered the idea of integrating a GUI into the TUI. The idea of combining TUI with GUI has been explored in other projects [5].

COMPARATIVE EVALUATION

The comparative evaluation was carried out to determine whether AC can be successfully used in chemistry lessons at a secondary school level. This empirical evaluation compared learning effectiveness and user acceptance (the dependent variables) of AC versus the BSM. The AC used was a version with a standard screen displaying a mirror view. The experiment was carried out at a secondary school with twenty-six biology and laboratory students, all in the first year of their secondary education (mean age=17,4, SD=1.8). The sampling consisted of 5 women and 21 men. The effect of the learning method (AC or BSM) on the dependent variables was measured repeatedly in an experiment of the AB-BA design (Fig. 2). The students were divided into two groups of equal size and worked individually with AC and BSM at two different times. One group used AC in a first session (week 1) and then the BSM in a second session (week 2). The other group used the systems in reverse order. Tasks given were related to smaller organic molecules and functional groups. The users' mood, mental task load, physical task load, satisfaction, perceived usability, and system preferences were measured using questionnaires and then converted into an assessment of user acceptance.

Experimental results

The results showed that subjects using the BSM solved the problems more effectively than those using AC. However, there was no significant difference in lesson retention, as measured in a subsequent test. Since most of the differences between the systems were related to the results on the subjective values we will focus on these in the remainder of this paper.

We present the outcome of three subjective rankings: NASA-TLX [4] applied to AC and BSM (Fig. 3), preference ranging by nine subjective criteria applied to AC and BSM (Fig. 4), and SUMI questionnaire [7] applied to AC only (Fig. 5). The NASA-TLX (Fig. 3) examined physical and mental demand. While physical demand was less for AC than BSM, all other demands were slightly higher for AC than for BSM. The greatest differences were seen in mental demand (F=3.93, p=0.05) and frustration (F=1.92, p=0.17). The preference ranking was measured by nine subjective criteria (Fig. 4). In terms of ease of learning the system, ease of use, helpfulness in problem-solving, and comfort of use, the BSM outperformed AC. In terms of enjoyability, visualization, content availability, future use, and effectiveness of learning, AC outperformed the BSM. The SUMI questionnaire applied to AC (Fig. 5) yielded the best value for learnability and the worst value for efficiency, with other values falling in between. SUMI is only applicable to software systems and so could not be applied to BSM.

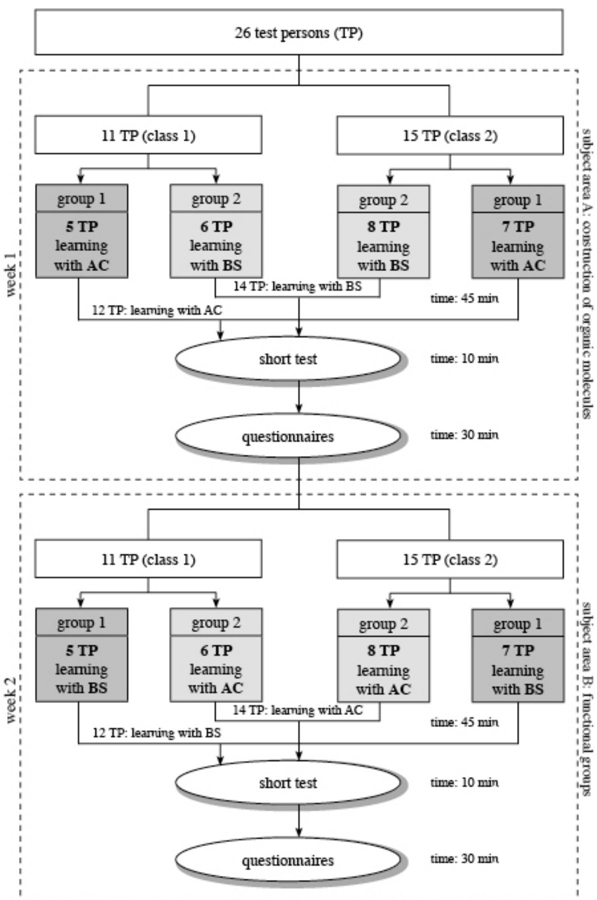

Figure 2: Effect of learning method (AC or BSM) on dependent variables was repeatedly measured in an experiment of the AB-BA design.

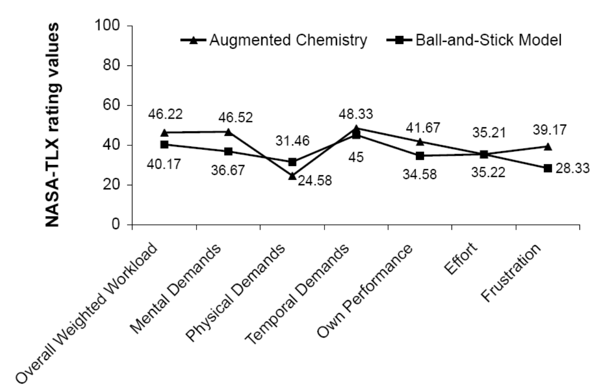

Figure 3: The NASA-TLX applied to AC and BSM.

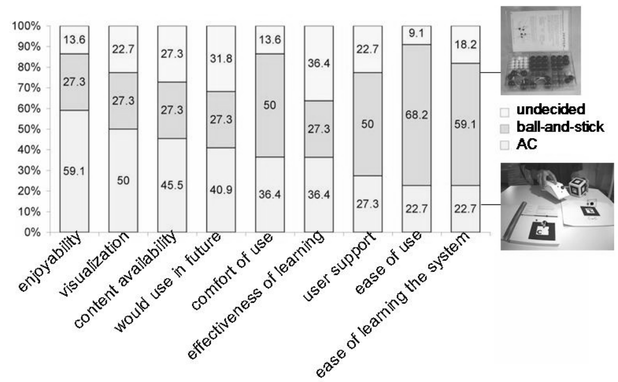

Figure 4: AC vs. BSM preference by nine criteria. Test subjects' mean preferences for AC (bottom), BSM (middle), or undecided (top).

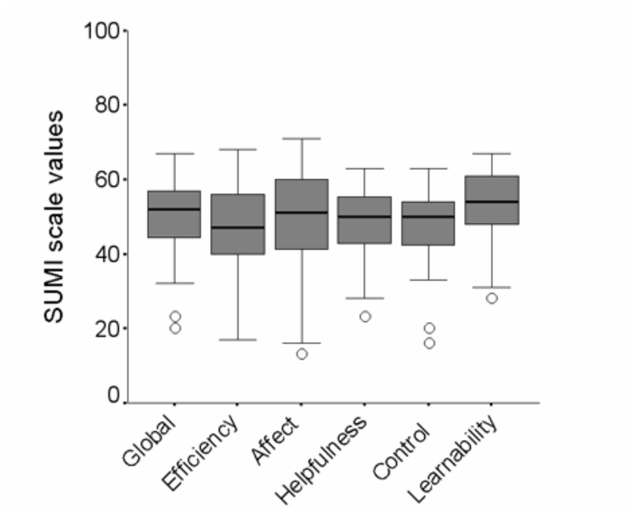

Figure 5: Outcome of the SUMI questionnaire for AC.

Subjective measures showed that the tested version of AC does not provide a learning environment superior to that of the BSM. In order to replace the BSM with AC, or to combine both, a higher user acceptance of AC is required. If its usability is improved and functionality enhanced, AC may potentially provide a learning experience superior to BSM. We assumed that a GUI would offer better user support and ease of learning the system, thereby reducing users' mental demand.

RE-DESIGN

The evaluation showed that a problem in using the AC system – as compared to a traditional BSM – was that controlling system settings often obstructed molecule construction [1]. Many configuration settings are more suited to a GUI, such as molecule size, element labeling, and system parameters. Such settings were initially mapped onto keyboard function keys. However, many users had difficulty using function keys while keeping complex chemical models in mind. The importation of molecules from external DBs also made it necessary to visualize large DB lists of molecules. So, to simplify interaction with system configuration settings and the new DB functionality, a purely mouse-controlled GUI was integrated into the primary TUI. Consequently, the GUI now allows for a much more user-friendly system. Plus, keyboard-free operation makes for more efficient use of tabletop real estate. To avoid a one-to-one reclaim of screen real estate, we designed a GUI with a permanent button in the corner that activates a pop-up menu with alternatives that activate graphic overlay dialogue boxes.

Along with these changes, the three-dimensional (3D) rendering was improved using shadows and related effects to enhance depth perception. Secondly, AC was ported to different operating systems and is now compatible with Linux-, Windows-, and Mac OS X based platforms. Finally, system capacity to import and visualize molecules from an extensive XML-based DB was realized. These issues, including GUI details, are described in a supplementary video presentation[2]. Next, we discuss issues concerning GUI/TUI integration and visualization.

GUI and TUI: design issues

Since OpenGL was already being utilized in AC for video image display and molecule rendering, it was the only application programming interface (API) feasible for GUI drawing. OpenGL has an adequate capability for high-quality GUI drawing because of its fast hardware acceleration. It is significantly faster than X or Win32 GDI when running on 3D-capable hardware. Alpha-blended texture mapping makes it possible to draw not only well designed 3D objects, but also smooth 2D windows and buttons. And a normal painting program is all that is required to customize the appearance in detail.

Alpha-blending also made it possible to easily implement the GUI's fading feature. When users click on the AC background video image, the entire GUI fades; when clicking anywhere on the translucent GUI, it regains full visibility. This effect would have been difficult to realize with most traditional windowing APIs. Since there was no suitable, light-weight GUI toolkit using OpenGL available under the GPL license, we implemented a toolkit designed in-house. We intend to base future GUI development on the current achievements.

The GUI's graphical overlay is utilized for the import function (Fig. 6, left), system configuration (Fig. 6, right), and as a browser for the internal molecule DB (Fig. 7, left). All the molecules loaded into the system, whether predefined or imported from external DBs, are indexed by their chemical name. This allows users to quickly browse through the molecules and select one by clicking its name. The browser then displays the selected molecule as a simplified 3D representation (Fig. 7, left).

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[2] Video of initial (2002) and of re-designed system (2005):
http://www.t2i.se/pub/media/2002-Fjeld_Voegtli-AC.mov
http://www.t2i.se/pub/media/2005_SIGRAD_AC.mp4

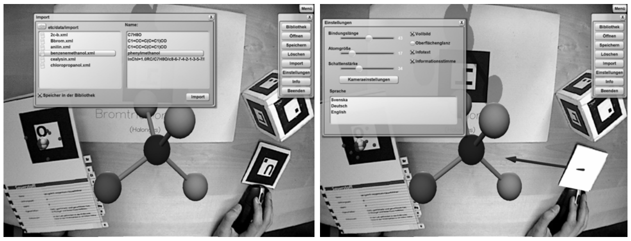

Figure 6: The GUI's import function from an external DB (left) and the GUI's configuration menu (right).

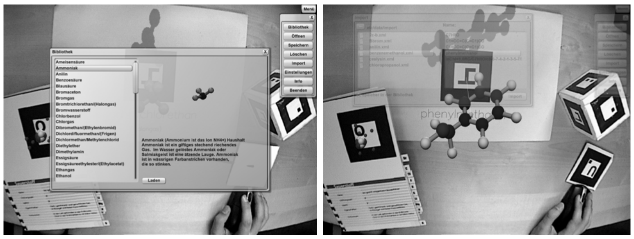

Figure 7: The GUI's molecule browser for the internal DB (left) and the focus shift from the GUI to the TUI

Improved 3D visualization and rendering

The user study [1] showed that manipulating the structure of the molecules using the TUI was relatively difficult. Small mistakes, e.g. misplacement and accidental removal of atoms, disrupted the process of constructing molecules. To increase the ease of learning and operating the system, we believe that the interface needs to feel more natural and more like the conventional BSM, but with the benefits of a TUI. To enhance the appearance of the computer-generated molecules, shadow rendering was added to the graphics engine. The projection of shadows and information on different planes (Figs. 6-7) lends a sense of order and structure to the complex information. Shadows play an important role in visualizing 3D models by improving the user's depth perception [8]. This may allow users to manipulate the molecules with greater precision, enhancing the TUI experience. However, when viewing more complex molecules, the shadows have little or no added value [9]. Addressing this issue, the system allows users to change the shadow darkness and turn it on or off easily.

Informal user study of re-designed system

To evaluate the re-designed system we conducted an informal user study in which six secondary school students worked with the old system, then with the re-designed system one month later. In both cases they constructed a set of molecules and then gave their subjective opinions about the system's ease of use, ease of learning the system, and future use. Most of their opinions on the old system confirmed the results reported by Bötschi [1].

Their opinions of the re-designed system indicated that we had successfully improved both the system's ease of use and ease of learning the system. Their general opinion was that the additional functionality and added features had increased the probability of their using a similar system in an actual learning situation. Some students found the re-designed system easy to understand, easy to navigate, and a good aid for memorizing molecular structures.

Discussion and outlook

Based on the AC system's first version and the outcome of its comparative evaluation [1], we have implemented a new set of functions and features into the system, as described in this paper. First, we have integrated a GUI into the TUI and improved 3D visualization and rendering. Then, we have extended portability to Windows and Mac OS X, enabling the use of different camera types. Finally, we have made AC compatible with an external XML database. We foresee a more extensive usability evaluation of the GUI/TUI integration and the GUI functionality in the future.

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