Revista de Ciencias Tecnológicas (RECIT). Universidad Autónoma de Baja California ISSN 2594-192
Volumen 4 (4): 412-424. Octubre-Diciembre, 2021 https://doi.org/10.37636/recit.v44412424.

Development of interactive gadgets: pedagogical, methodological and ergonomic aspects for industrial design

Desarrollo de gadgets interactivos: aspectos pedagógicos, metodológicos y ergonómicos para el diseño industrial

Alejandro Daniel Murga González, Génesis Rubí Nájera Morga, Camilo Caraveo Mena

Facultad de Ciencias de la Ingeniería y Tecnología, Universidad Autónoma de Baja California, Unidad Valle de las Palmas, Tijuana, Baja California, México

Corresponding author: Alejandro Daniel Murga González, Facultad de Ciencias de la Ingeniería y Tecnología, Universidad Autónoma de Baja California, Unidad Valle de las Palmas, Tijuana, Baja California, México. E-mail: alejandro.murga@uabc.edu.mx. ORCID: 0000-0002-5840-1822.

Received: September 20, 2021 **Accepted:** December 12, 2021 **Published:** December 16, 2021

Abstract. - *The Industry 4.0 is a consequence of the evolution in technological advances, which has allowed and the use of new tools for simulation, digital integration, fabrication flexibility, and personalization to achieve new product design solutions. The importance and actuality of this revolution have had a great impact on the engineering and design education system, and this is the case of the Faculty of Engineering and Technology Sciences (FCITEC), from the Autonomous University of Baja California (UABC), where the implementation of gadget prototyping has been encouraged. This ongoing work is intended to delineate the methodological, pedagogical, and ergonomic aspects of gadget prototyping with platforms such as Arduino and NodeMCU, and its benefits to the Industrial Design (ID) Discipline. It is a project that started in 2018 with the scope of understanding interactivity, usability, and multidisciplinary collaboration, which are key for a designer's profile. In this sense, User-Centered Design methodology is used as a framework for usable product development, with the aid of task, interface, and housing design. Specific tools of particular interest are persona design, interface analysis, and cognitive architecture outline. Important results so far include 1) student-made prototypes, 2) usability workshops in international congresses, 3) intellectual property registration, and 4) academic course designs.*

Keywords: User centered design; Usability; Gadget prototyping; Arduino; NodeMCU.

Resumen.- La Industria 4.0 es consecuencia de la evolución de los avances tecnológicos, que ha permitido el uso de nuevas herramientas para la simulación, integración digital, flexibilidad y personalización de fabricación para lograr nuevas soluciones de diseño de productos. La importancia y actualidad de esta revolución ha tenido un gran impacto en el sistema educativo de ingeniería y diseño, y este es el caso de la Facultad de Ciencias de la Ingeniería y Tecnología (FCITEC), de la Universidad Autónoma de Baja California (UABC), donde se ha fomentado la implementación de prototipos de dispositivos. Este trabajo en curso tiene como objetivo delinear los aspectos metodológicos, pedagógicos y ergonómicos de la creación de prototipos de dispositivos con plataformas como Arduino y NodeMCU, y sus beneficios para la disciplina de diseño industrial (ID). Es un proyecto que se inició en 2018 con el objetivo de comprender la interactividad, la usabilidad y la colaboración multidisciplinar, que son claves para el perfil de un diseñador. En este sentido, la metodología de Diseño Centrado en el Usuario se utiliza como marco para el desarrollo de productos usables, con la ayuda del diseño de tareas, interfaces y carcasas. Las herramientas específicas de particular interés son el diseño de personas, el análisis de interfaces y el esquema de arquitectura cognitiva. Los resultados importantes hasta ahora incluyen 1) prototipos hechos por estudiantes, 2) talleres de usabilidad en congresos internacionales, 3) registro de propiedad intelectual y 4) diseño de cursos académicos.

Palabras clave: Diseño centrado en el usuario; Usabilidad; Prototipos de gadget; Arduino; NodeMCU.

1. Introduction

The development of interactive gadgets such as wearable devices and similar products bring diverse fields together, such as software engineering, industrial design, mechatronics, and others; and thus, require collaborative multidisciplinary action, which the electronics industry has mastered and is yet to be consolidated in pre-grad education. Authors [1-12] that come from computer science disciplines and psychology have outlined frameworks such as User Centered Design (UCD), Human-Computer Interaction (HCI) and Cognitive Ergonomics, and established rules for interface design that are yet to be assimilated by ID students.

For that reason, at the Autonomous University of Baja California (UABC) in the ID Department academics are beginning to adopt methodological and pedagogical approaches to work with platforms such as Arduino and NodeMCU [13-17]. This ongoing work is intended to delineate the **methodological, pedagogical and ergonomic** aspects of gadget prototyping with this platform, and its benefits to the ID discipline. It is an academic and curricular project that started in 2018 with the scope of understanding interactivity, usability and multidisciplinary collaboration, which are key for the designer's profile. In this sense, UCD methodology [18-22] is used as a framework for usable product development, with the aid of task, interface and housing design. Specific tools of particular interest are persona design, interface analysis and cognitive architecture outline. Important results so far include 1) student-made prototypes, 2) usability workshops in international congresses, 3) intellectual property registration, and 4) academic course designs.

To illustrate the aforementioned, a student-made prototype is presented. The project is called "Music House", a preschooler/early elementary toy designed for learning letters and words. In this work the user centered design methods implemented are described and the pedagogical framework that supports them is outlined.

2. Theoretical framework and pedagogical aspects

It is convenient to mention the theoretical base that supports this study. On the one hand, the Systems Theory [23-24]; and Cybernetics and Communication Theory [25-26] provide guiding concepts such as interactivity, input, output and feedback. On the other hand, Ergonomics [27] help narrow down the interacting elements human-object-task-environment within a system, where overall performance and human wellbeing are major goals. These concepts are part of the base of design fields such as Experience Design, Emotional Design, Interaction Design and UCD, and help to analyze the human-gadget interaction (Figure 1).

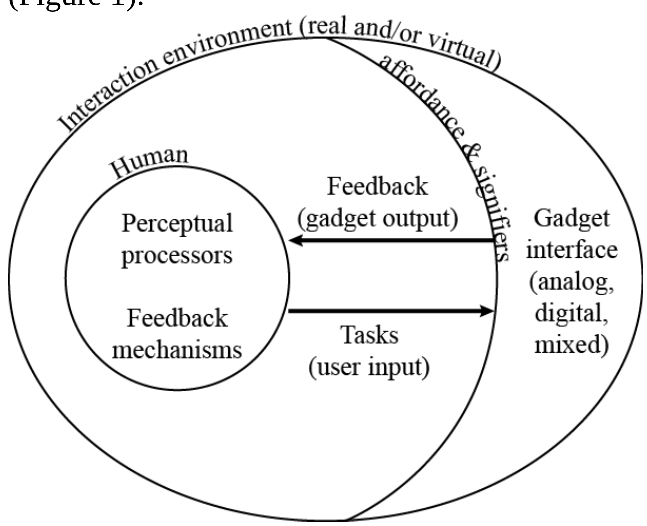

Figure 1. Human-gadget interaction representation.

The Human-gadget interaction representation was developed on 2019 by professors in the ID department at FCITEC and has served as a research/educational outline for students in order to understand ergonomic systems where

ISSN: 2594-1925

interaction and communication flow are key analytical concepts; and has helped to build the pedagogical material for the courses "Usability Assessment for Industrial Designers" and "Gadget Development and Prototyping", which are currently offered at the faculty, subjects that are unique from the design perspective and are not offered in other campuses for the ID program. This is particularly important because gadget prototyping is not common in the ID programs in Mexico.

3. Methodology: prototype development

"Music House" is a gadget prototype that was developed along the teaching of four courses of the Industrial Design program at UABC FCITEC: Design Workshop V, Design Methodology III, Usability Assessment for Industrial Designers, and Gadget Development and Prototyping. Throughout these courses several user research methods applied in the field of design were implemented in order to develop fully functional technological devices. These methods come from diverse disciplines such as software design, ergonomics and UX/UI design, which include cognitive task analysis, user personas and cognitive architecture modelling; and are used to analyze and design user interfaces. Some of these methods are described in their application to develop "Music House" as follows.

3.1 User Personas

Considering the amount of information traces that internet users leave, it is expected to be used as input for product and service design. With this in mind, user personas [28-29] represent large segments of the population that share qualities that are translated to design decisions that will help the product to be successful in desirability, functionality, and other aspects. It can be said that "Personas are based on the behaviors and motivations of real people we have observed and represent them throughout the design process" [30, p. 75].

Personas, along with documentary research, were used to define the "Music House" users, narrowed down as 4-7-year-old infants, preschoolers and early elementary schoolers that are learning how to write. Learning in this age group is often aided with ludic exercises and games, which consist in pattern learning through music, images and symbols.

With these characteristics in consideration, the principal concern in "Music House" is the child's cognitive development, centered in the emergent alphabetization process, that is to say reading and writing as activities that emerge within the child and occur in relation to language experiences. For that reason, it is advisable to have (or design) an interactive environment [31].

Children from 3-5 years of age experience a rapid development of linguistic, socioemotional and cognitive competences; and for that reason it is important to promote the use of creativity and imagination with learning stimuli through playful activities, singing and reading [32]. This is the base for "Music House" user requirements, that pointed to a musical toy that helps to learn words through kinetic, acoustic and visual activities.

3.2 Cognitive Task Analysis

Cognitive task analysis (CTA) methods are used to understand the complexity of user activities and are widely used across disciplines. In ID, CTA are used as a non-empirical usability method to help the designer outline the relationship between the interface (digital or analog) and the user. With this information, it will be clearer to define the quantity of steps to perform a task and the interaction with controls (i.e. buttons, handles, etc.). According to Klein

ISSN: 2594-1925

and Armstrong [33] CTA methods are highly adaptable and adjustable because they are used to make new discoveries every time, which means that the phenomena of interest are not well known at the outset of the research.

According to Jordan [34, p. 73] "task analyses alone refer to the physical steps or the physical interaction user-object, and are verbalized in notations (i.e. tasks broken in sub-elements and how the measure of the task complexity is derived)". These methods are used to investigate whether its interface demonstrates the design properties of consistency and compatibility.

CTA was used in "Music House" to help the ID student define step by step the playful tasks before exploring in depth the interface design. Activities such as the use of cards to play music and the use of chips to build words were firstly outlined and analyzed with this method in order to make them coherent and fluid (Figure 2).

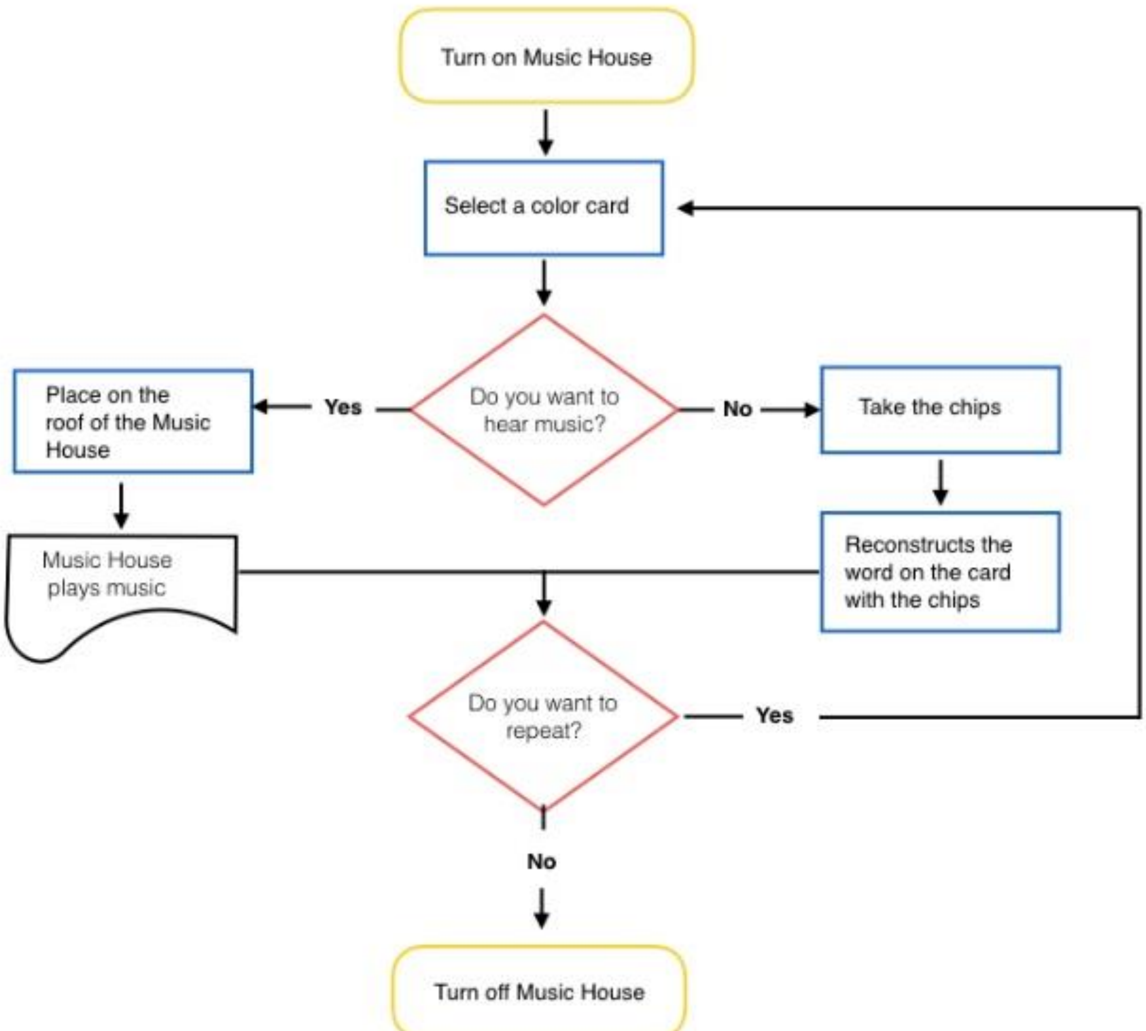

Figure 2. Cognitive task analysis of Music House flowchart.

ISSN: 2594-1925

With this in mind, objective of "Music House" as a pedagogical toy is to learn to relate letters with words and objects. The child is supposed to choose a color card and place it on the top of the toy to reproduce a song about objects that match the color of the cards, as shown in Figure 2. The flowchart illustrates the tasks and decisions that the user makes interacting with the toy.

3.3 *Cognitive architecture modelling*

For product design, modelling the cognitive architecture [35-36] allows to visualize the physical interactions between the user and the object's interface in terms of communication, highlighting the flow of information that is needed to complete the task. In that sense, designers can identify the user sensory channels in order to create suitable optical, haptic and acoustical interactions.

The "EPIC (Executive/Process-Interactive Control) is a cognitive architecture especially suited for modeling human multimodal and multiple-task performance" [37, p. 391].

The EPIC architecture was used in "Music House" as a tool for linking the user's sensory channels with physical parts (i.e. buttons, handles, grips, etc.) and helped to make design decisions for the affordances: for example, choosing flashing buttons, because they seem inviting; or implementing an invisible interface (i.e. interactions happen without touching the object) for the cards, which are presented over a mark on the house's roof in order to play the music, because a kinetic activity helps as a complement for learning (Figure 3).

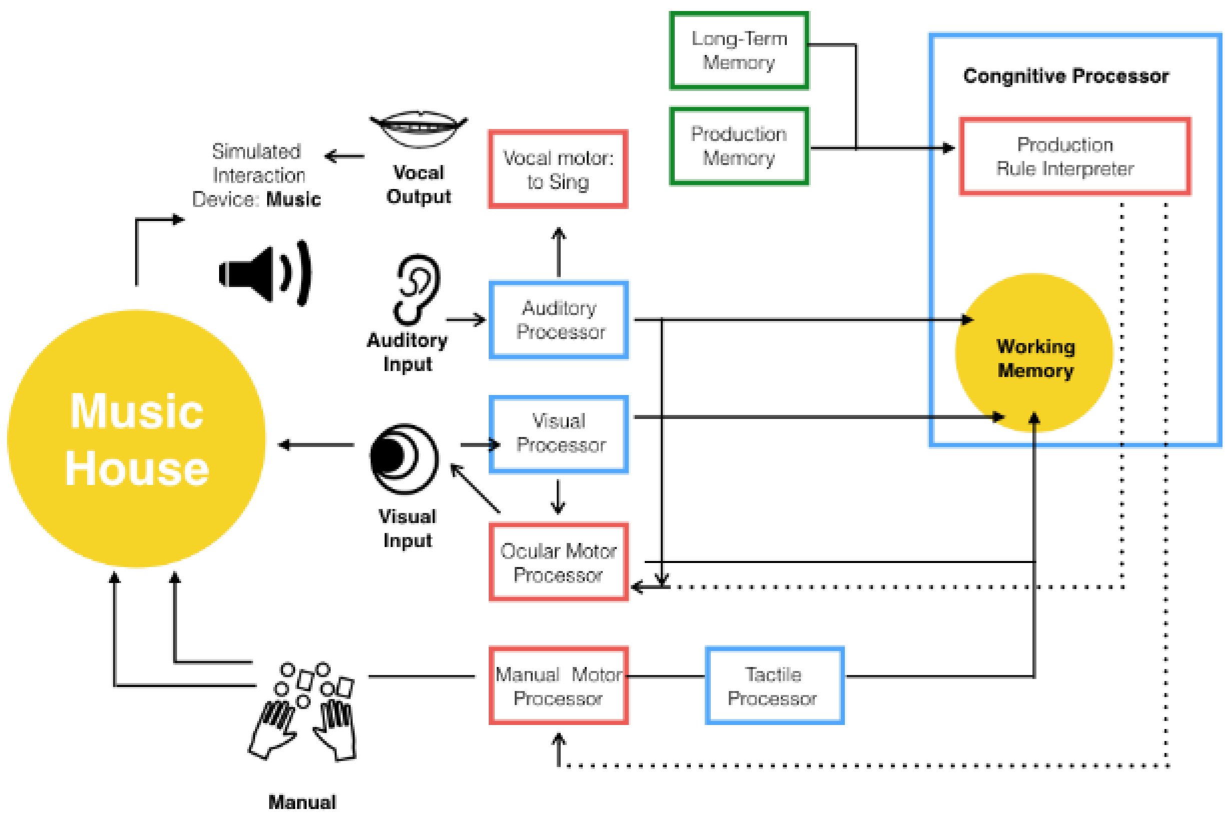

Figure 3. Cognitive architecture representation of the "Music House" project, developed with Arduino done by a student, based on [37].

ISSN: 2594-1925

The cognitive architecture in “Music House”, as shown in the Figure 3, is modelled considering the flow of information based on cues and repetitions in order to assist the child in its learning process at this early stage. In other words, “Music House” *tells* the child how to pronounce letters and words by saying them out loud.

3.4 Interface analysis and design

The interface design in “Music House” includes the analysis of the principles and elements of design that have impact in the user’s sensory channels in terms of sounds, images, tactile experiences and others. This analysis considers linguistic (verbal) and non-linguistic (haptics, optics, acoustics, proxemics, kinetics, and other) signs. Modifiers of these signs include tone, velocity, intensity, balance, emphasis, harmony, variety, gradation (Figure 4).

Particularly speaking, design elements that have impact in the optical aspect are color, shape/figure, line, texture and space. With this in mind, a designer can make conscientious decisions of how the interface will be configured to provide the desired experience, for instance: a non-linguistic optical sign such as the red color in a light alarm can have a great impact in communicating a warning.

The interface analysis in “Music House” serves as a complement for the cognitive architecture modelling because it widens design possibilities for interface elements. In this case, it helps to decide about the type of music, lettering, symbols, colors, combining principles and elements of design.

In this case, “Music House” only presents colors in the drawings and in the buttons, leaving the rest of the toy with the natural material appearance, with the purpose of making an emphasis to the sources of information to draw the user’s attention. Also, drawings, letters and the general housing present curvy lines, forms and figures to denote the playful aspect of the toy.

Non-linguistic outline			
Haptics/ Acoustics/ Optics	Proxemics	Kinetics	Other signs
Speakers, cards, buttons, lights, textures, colors	Toy dimensions and disposition in space	Movements with music	Symbols
Linguistic oultine			
Verbal		Paralinguistic	
Written (cards) Oral (speakers)		Tone, velocity intensity in voice (speakers)	

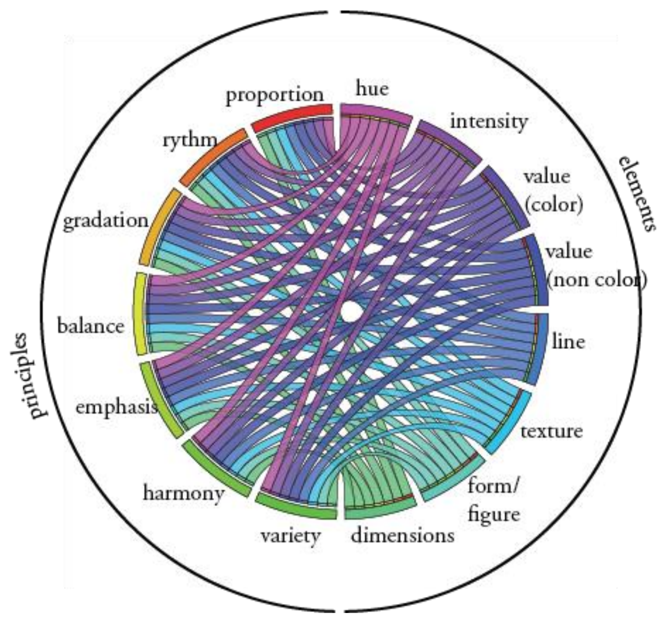

Figure 4. Non-linguistic and linguistic outlines in “Music House”, based on [38] / Possible combinations of principles and elements of design.

ISSN: 2594-1925

4. Fabrication and ergonomic aspects of prototyping in ID education

As shown in the Figure 5, “Music House” consists of a house-shaped box that contains a speaker, volume buttons and a sensor to detect cards that activate the reproduction of sounds and music related to words and letter pronunciation. On the one hand, the housing is small for the user to manipulate and transport with ease and is designed based on geometric figures. On the other hand, the cards have either drawing of animals based on primary and secondary colors or letters with simple yet playful typography. Said cards have rounded angles for safety and are shaped in trapezes to connect letters and thus form words.

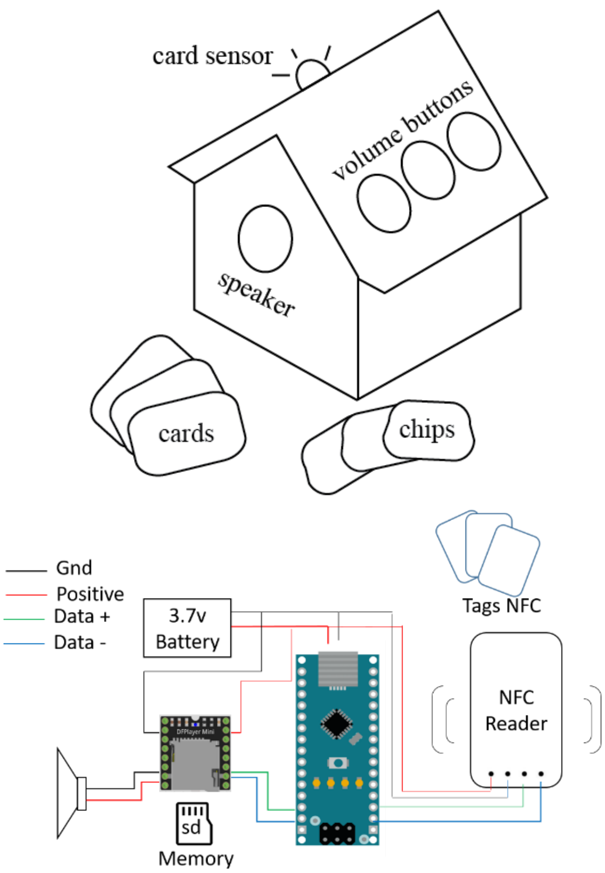

Figure 5. Music House diagram / The electronic prototyping was done with the pedagogical platform *Tinkercad* and Arduino.

The prototype is fabricated with Medium-density fiberboards (MDF) through Computer Numerical Control (CNC) machining for its housing; and with extruded polylactide (PLA) for 3D printed accessories such as handles. Prefabricated electronic elements were used along with the Arduino microcontroller. These materials were selected according to the feasibility of manufacture in the faculty’s facilities and considering the user’s safety. Being specific, MDF and PLA are nontoxic low-cost materials that are easy to handle in rapid prototyping.

In terms of the electronic prototyping, the integration was done with Arduino and with *Tinkercad* [39], a free-of-charge, online 3D modeling program that runs in a web browser, that is being used in schools as a pedagogical tool, and allows the students to simulate connections and functions without the risk of damaging the physical components (Figure 5).

The use of educational tools such as Arduino and Tinkercad can be seen as ergonomic in the aspect of design practice because they assist the rapid prototyping of electronics in several ways: it makes the development shorter, it allows to test before prototyping, and allows to understand the integration better, as it gives a clear idea of how the final pre-production prototype will look like. Being specific, and under the usability concepts of effectivity (accomplishment), efficiency (resources) and satisfaction (learning), “Music House” proves to be a project that helps to understand complex concepts with few resources -materials and working tools can be provided at FCITEC; and finish a complete project in 4 months. “Music House” serves as an educational ID material for future student projects, helping them to understand basic electronic principles, dimensions, and integration.

ISSN: 2594-1925

5. Results

The result of this project is a fully functional prototype which can be categorized considering three variables: housing design, electronic building and integration. These categories are based on the Industrial Designers Society of America (IDSA) [40] taxonomy, which helps to clarify the differences between several types of models and prototypes. As the Figure 6 shows, the Music House prototype has a medium complexity in housing design and is located in an early stage of development in electronics prototyping and overall integration.

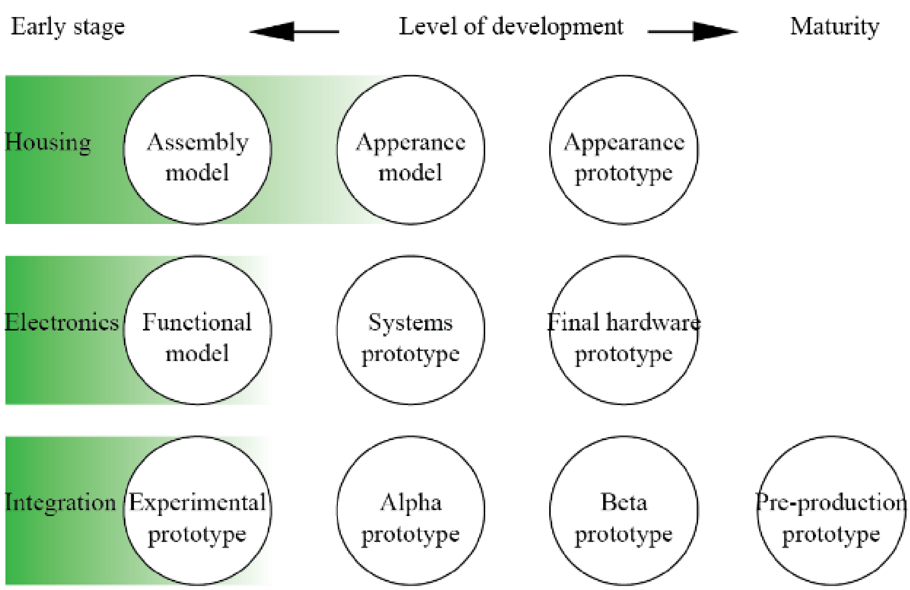

Figure 6. Level of complexity of Music House prototype based on the IDSA taxonomy.

5.1 Methodological, pedagogical and ergonomic contributions

"Music House" project serves three purposes: first, and on the pedagogical aspect, it helped to unify the theories and concepts of the courses Design Workshop V, Industrial Design Methodology III, Usability Assessment for Industrial Designers and Gadget Development and Prototyping in one single project. This helps to guide students and motivate them to carry on projects like this, as they can produce enough information to structure a pregrad thesis project. Second, and in the methodological aspect, it helped to structure an instructional design for gadget prototyping. Also, it will help to document future similar projects based on gadget prototyping using these UCD methods under the ID perspective. It is worth mentioning that ~~for~~ there is a lack of pedagogical material for this discipline in terms of designing with platforms such as Arduino or NodeMCU. In this sense, "Music House" lays a precedent in terms of education and methodology.

Third, and on the ergonomic aspect, "Music House" adapts ergonomic methods that are common in UX (software) design to analog interface design, and illustrates how cognitive ergonomics is put into practice from the ID perspective.

ISSN: 2594-1925

This project documents every process of the product design process, from a multidisciplinary perspective, including areas from cognitive ergonomics, UI/UX design and manufacturing. The contribution is to have brought these methods from different disciplines into one academic project and its use as teaching material in the industrial design curriculum for interactive product development. With this in mind, the aim is to structure a formal methodology for this discipline and allow the future designers to create fully functional gadgets by themselves with the user centered design perspective.

The actual paradigm of the design process taught in universities overlooks the user interaction and experience. It is not that it is regarded as unimportant, but because there is little work with electronics, which can be used as a tool to illustrate concepts that inform user research and come from other disciplines such as algorithms, tasks, interaction, cognition, etc.

Since 2018, electronic prototyping has been encouraged at UABC to enhance the designer's professional profile and its benefits become visible through many aspects. For instance, in March 2019, a usability workshop was carried out in the International DI Integra Congress, organized by the national association of Industrial Design schools. Students form several universities nationwide attended the workshop to reflect on the importance of user testing and had the opportunity to evaluate electronic prototypes made by UABC students (Figure 7). The activities were based in the course Usability Assessment for Industrial Designers, that is actually offered in the Engineering and Technology Sciences Faculty at UABC.

Also, it is important to mention the technical documents such as plans and other industrial drawings made for "Music House" are being evaluated to be subject of intellectual property protection by the National Institute of Copyright in Mexico.

Figure 7. Usability workshop UABC with student-made prototypes. Photography taken by Andrea Lozano López (andrea.loz1997@gmail.com).

All of this has made an impact in the new study plan for the Industrial Design program at UABC which is now active, and aims to be at the forefront in terms of working with the industry 4.0 technology.

6. Conclusions

The "Music House" project contributes in the ID discipline in pedagogical, methodological and ergonomic aspects. First, the human-gadget interaction research/educational outline serves an approach for research and design activities related to gadget design. It strengthens the ID curriculum and allows to offer unique courses at FCITEC. Second, the design methodology used for this project helped to define the user profile, outline the basic user activities, select affordances and design the analog interface:

(1) The User Persona method clarified how the user characteristics research laid the base of the user requirements.
(2) The Cognitive Task Analysis, helped to outline the basic playful activities of the toy.

ISSN: 2594-1925

(3) The Cognitive architecture modelling aided in deciding the broad physical design aspects of the toy (i.e. use of flashing buttons and implementation of an invisible interface).
(4) The Interface analysis helped to choose and combine design principles and elements to make specific decisions in the ergonomic, communicative, and aesthetical aspects.

Third, the modelling, simulation and fabrication tools prove to be feasible for rapid prototyping in the ID program, helps the student to succeed in building a conceptual prototype as learning evidence, and makes the pedagogic strategy in design ergonomic to understand complex concepts in a short time and with few resources.

The importance of teaching students a multidisciplinary approach to the design process is key to overcoming the product design paradigm, limited to traditional industrial processes. The industry nowadays needs professionals that can make possible the dialogue between design and engineering in terms of rapid prototyping of technological devices. Tijuana, like many other Mexican cities, is shifting from solely product assembly towards local product design. Also, in the frame of the industry 4.0., Industrial Designers will be required to know basic aspects of electronics and programming.

This has been the case of the Industrial Design program at FCITEC, that offers 9 engineering and 3 design programs, which allows the students to easily generate multidisciplinary projects, with the aid of professors with diverse backgrounds., Professors formed in the areas of architecture, industrial design and software design participated in for this particular project.

The scope of these efforts is to continue expand the ID professional credentials to adapt to the new 4.0 industry requirements. Specifically, it is planned to keep on developing digital gadgets at FCITEC for several reasons: (1) structure a pedagogical handbook for designers; (2) keep on registering industrial designs and promote the transfer of technology and knowledge; (3) and apply this design and fabrication methodology on different types of gadgets in order for its enhancement.

As a final remark, it is convenient to say that teaching digital prototyping to design students will not only make them suitable to the developing job market, which asks more digital and technological competencies, but will enable them to start new business and self-employ.

7. Acknowledgment

To the Faculty of Engineering Science and Technology, for providing the facilities and also to the teachers and students for participating in the development of this technological project.

8. Authorship acknowledgment

Genesis Rubí Nájera Morga: Conceptualización, Recursos, Ideas, Análisis formal, Investigación, Escritura, Análisis de datos, Revisión y edición. *Alejandro Daniel Murga González:* Conceptualización, Recursos, Ideas, Análisis formal, Investigación, Escritura, Análisis de datos, Revisión y edición. *Camilo Caraveo Mena*: Metodología, Investigación, Análisis de datos, Revisión y edición.

References

[1] Cheriton, D. R. "Man-machine interface design for timesharing systems", Proceedings of the 1976 annual conference. ACM, pp. 362-366. October 1976. https://doi.org/10.1145/800191.805617

ISSN: 2594-1925

[2] Norman, D. A. "Design rules based on analyses of human error", Communications of the ACM, 26(4), 254-258. 1983. https://doi.org/10.1145/2163.358092

[3] Smith, S. L., & Mosier, J. N. "Guidelines for designing user interface software" (No. MTR-10090). Bedford, MA: Mitre Corporation, 1986. https://doi.org/10.21236/ADA177198

[4] Shneiderman, B. "Designing the user interface: strategies for effective human-computer interaction". Pearson Education India, 2010. https://www.pearson.com/us/higher-education/program/Shneiderman-Designing-the-User-Interface-Strategies-for-Effective-Human-Computer-Interaction-6th-Edition/PGM327860.html

[5] Marlin, C., & Brown, L. "Human-computer interface design guidelines". Ablex Pub.: Norwood, NJ, 1988. https://dl.acm.org/doi/10.5555/38160

[6] Hollnagel, E. Cognitive ergonomics: it's all in the mind. Ergonomics, 40(10), 1170-1182, 1997. https://doi.org/10.1080/001401397187685

[7] Durso, F. T., Nickerson, R. S., Dumais, S. T., Lewandowsky, S., & Perfect, T. J. (Eds.). Handbook of applied cognition. John Wiley & Sons, 2007. https://doi.org/10.1002/9780470713181

[8] Molich, R., & Nielsen, J. Improving a human-computer dialogue. Communications of the ACM, 33(3), 338-348, 1990. https://doi.org/10.1145/77481.77486

[9] Neisser, U. Multiple systems: A new approach to cognitive theory. European Journal of Cognitive Psychology, 6(3), 225-241, 1994. https://doi.org/10.1080/09541449408520146

[10] Norman, D. A. User centered system design: New perspectives on human-computer interaction. CRC Press, 1986. https://doi.org/10.1201/b15703

[11] Rowlands, M., & Mark, R. The body in mind: Understanding cognitive processes. Cambridge University Press, 1999. https://doi.org/10.1017/CBO9780511583261

[12] Shneiderman, B., Plaisant, C., Cohen, M. S., Jacobs, S., Elmqvist, N., & Diakopoulos, N. Designing the user interface: strategies for effective human-computer interaction. Pearson, 2016.

[13] Al Dahoud, A., & Fezari, M. NodeMCU V3 For Fast IoT Application Development. Notes, 2018.

[14] Peláez, J. P. Internet de las cosas (IoT) con Arduino. Manual práctico. de NodeMCU, Madrid, Paraninfo, 5-8, 2019

[15] Kurniawan, A. Internet of Things Projects with ESP32: Build exciting and powerful IoT projects using the all-new Espressif ESP32. Packt Publishing Ltd., 2019

[16] Hoddie, P., & Prader, L. IoT Development for ESP32 and ESP8266 with JavaScript: A Practical Guide to XS and the Moddable SDK. Apress, 2020 https://doi.org/10.1007/978-1-4842-5070-9

ISSN: 2594-1925

[17] Monk, S. Programming Arduino: getting started with sketches. McGraw-Hill Education, 2016.

[18] Abras, C., Maloney-Krichmar, D., & Preece, J. User-centered design. Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications, 37(4), 445-456, 2004.

[19] Bevan, N. International standards for usability should be more widely used. Journal of Usability studies, 4(3), 106-113, 2009.

[20] Maguire, M., Kirakowski, J., & Vereker, N. (1998). RESPECT: User centred requirements handbook.

[21] Maguire, M. (2001). Context of use within usability activities. International journal of human-computer studies, 55(4), 453-483. https://doi.org/10.1006/ijhc.2001.0486

[22] Maguire, M. (2001). Methods to support human-centred design. International journal of human-computer studies, 55(4), 587-634. https://doi.org/10.1006/ijhc.2001.0503

[23] Gibson, J. E. How to do systems analysis (Vol. 47). John Wiley & Sons, 2007. https://doi.org/10.1002/9780470130599

[24] Stichweh, R. (2008). Systems Theory. Retrieved April 1, 2015, from http://www.fiw.uni-bonn.de/de-mokratieforschung/personen/stichweh/pdfs/80_stw_systems-theory-international-encyclope-dia-of-political-science_2.pdf/view

[25] von Bertalanffy, L. General system theory: foundations, development, applications (Rev. ed..). New York: GBraziller, 1973.

[26] Wiener, N. Cybernetics; or, Control and Communication in the animal and the machine. (2d ed..). New York, MITPress, 1961. https://doi.org/10.1037/13140-000

[27] EA. Definition and Domains of ergonomics | IEA, 2000. Website. Retrieved September 8, 2015, from http://www.iea.cc/whats/index.html

[28] Miaskiewicz, T., & Kozar, K. A. (2011). Personas and user-centered design: How can personas benefit product design processes? Design studies, 32(5), 417-430. https://doi.org/10.1016/j.destud.2011.03.003

[29] Moser, C., Fuchsberger, V., Neureiter, K., Sellner, W., & Tscheligi, M. (2012). Revisiting personas: the making-off for special user groups. In CHI'12 Extended Abstracts on Human Factors in Computing Systems (pp. 453-468). https://doi.org/10.1145/2212776.2212822

[30] Cooper, A., Reimann, R., & Cronin, D. "About face 3: the essentials of interaction design". John Wiley & Sons, 2007.

[31] Navarro, E. B. Alfabetización emergente y metacognición. Revista signos, 33(47), 111-12, 2000. https://doi.org/10.4067/S0718-09342000000100010

[32] UNICEF. (2017, October). Aprendizaje a través del juego. 2021, de UNICEF Available: https://www.unicef.org/sites/default/files/2019

ISSN: 2594-1925

-01/UNICEF-Lego-Foundation-Aprendizaje-a-traves-del-juego.pdf

[33] Klein, G., Armstrong, A. "Critical Decision in Human factors methods: a practical guide for engineering and design "in Handbook of human factors and ergonomics methods. CRC Press, 2017.

[34] Jordan, P. An introduction to usability. CRC Press, 2020. https://doi.org/10.1201/9781003062769

[35] Kieras, D. E. A summary of the EPIC Cognitive Architecture. The Oxford handbook of cognitive science, 1, 24, 2016. https://doi.org/10.1093/oxfordhb/9780199842193.013.003

[36] Byrne, M. D. (2007). Cognitive architecture. In The human-computer interaction handbook (pp. 119-140). CRC Press. https://doi.org/10.1201/9781410615862.ch5

[37] Kieras, D. E., & Meyer, D. E. An overview of the EPIC architecture for cognition and performance with application to human-computer interaction. Human-Computer Interaction, 12(4), 391-438, 1997. https://doi.org/10.1207/s15327051hci1204_4

[38] Rizopoulos, C., & Charitos, D. Implications of theories of communication and spatial behavior for the design of interactive environments. In 2011 Seventh International Conference on Intelligent Environments (pp. 92-99). IEEE, 2011. https://doi.org/10.1109/IE.2011.57

[39] Kelly, J. F. 3D Modeling and Printing with Tinkercad: Create and Print Your Own 3D Models. Que Publishing, 2014.

[40] Evans, M. How they do it, International Designers Society of America, IDSA. Accessed on: September. 20, 2021. [webpage]. Available: https://www.idsa.org/education/how-they-do-it

ISSN: 2594-1925