Integrating Makerspaces in Higher Education: Constructionism Approach to Learning

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Abstract This study explored the impact of using makerspaces in higher education. The paper sought to investigate the effects of constructionism approach on students learning outcomes in the setting of makerspaces which allows community members to design, prototype and manufacture items using tools that would otherwise be inaccessible or unaffordable such as 3-D printers, laser cutters, CNC machines, and CAD/CAM software. The case study involves students in the Design Program at Effat University, Jeddah, Saudi Arabia. In such a makerspaces environment, results based on course learning outcomes in product design showed that students perform better learn creative ways to problem-solving, and engage effectively through creative experimentation. Further empirical research into the effectual relations between design and 3D constructions may further demonstrate the vital importance of makerspaces on students' learning performance and mastery of skills in the context of higher learning.

1 Introduction

The development and easy access to new technology continue to have an impact on teaching and learning methodologies [1–4]. Makerspaces known as hackerspaces, hack labs, or FabLabs, is a novel approach of product development carried out in an atmosphere of shared interests, thinking, knowledge, resources, and equipment,

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especially in computing or technology, which encourage learners to design, experiment, and build, thus facilitates interactive participation in innovative development while leading to new business and economic ventures [5–7]. Makerspaces can be defined as a physical location where learners or community members gather and share knowledge and tools to develop, innovate, and create solutions [8, 9]. Makerspaces also represent one of the integral parts of a modern education system that brings together and facilitates the community of interdisciplinary individuals.

Makerspaces improve students' learning when makerspace used. They provide places for people to work on hands-on projects building in a setting of community. The maker movement attracts more individuals into product design, generates dense but diverse networks, creates new ideas and innovative thinking, and lowers the costs for prototyping [8]. According to Saorín et al. [9], the emergence of education with digital fabrication techniques offers an opportunity for the development of creativity. For them, research results show that activities with digital editing tools and three-dimensional printing are valid for the development of creative competence [9].

Makerspaces also prove to be a powerful tool to teach design and manufacturing concepts in parallel, which is especially important for product designers, and is also believed to help students develop their personal soft skills, such as teamwork, communication and learning to work with students from other fields while also building physical prototypes for research projects and their theses [10]. Fisher [11] argued that Maker spaces and the integration of 3D printing provide ample opportunities for students to use critical thinking and problem solving, and further engage students in hands-on learning and experimentation [11].

The key point is that learning through making new constructions, as Papert [12] explained in his theory of constructionism. This learning-by-making is in line with Piaget [13] experiential learning theory where people learn effectively through making things. In the makerspaces sphere, this movement has been recognized to have its root in the learning theory of Papert's constructionism as reported by Martinez and Stager in their book [14] "Invent to Learn: Making, Tinkering, and Engineering in the Classroom". Martinez and Stager argued that makers construct knowledge as they build physical artifacts with real-world value. The culture or rather mindset of maker space can be described as a medium for cross-curricular, higher-order thinking in the classroom. Makerspaces are not only about a space being used by participants to engage in making, but also seen as a mindset [15].

In our context of learning, students are encouraged to acquire increased exposure to the environment of scientific engagement, innovative thinking, and creativity in order to promote the development of maker experiences. This started in a learning space FabLab, as model fabrication unit at Effat University. With emphasis on constructionism theory [12] where learning is positioned in the context of social participation and individual knowledge, the FabLab attracts students from different engineering and technology academic fields, and echoes the objective set by the Accreditation Board for Engineering and Technology (ABET) which states as follows: "provides students with technology, manufacturing equipment and the ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability".

The basic objective of the FabLab is to enhance students' ability to produce professional and accurate models and hosts different design machines such as laser cutting machine which helps students accelerate the process of model-making, materials such as wood, acrylic, cardboard, and MDF which can be engraved quickly and precisely by means of AutoCAD drawings, 3D printers producing complicated prototypes. Students can also use software like as Sketch Up, 3D AutoCAD, Solid works and 3D Max to prepare their own 3D files and be able to export data as STL files to available printers. Because the 3D printers can produce more complicated shapes, students are able to combine larger scale models with the laser cutters and then add more detailed and complex components to them. 3D printers and laser cutter are considered the most common equipment used in makerspaces labs as reported by the American Society for Engineering Education [16].

This study explored the advantages of using makerspaces for students in the design program and sought to investigate some of the best practices of constructionism approach to learning and its impact on students' learning (Fig. 1).

Fig. 1 FabLab Effat University, Jeddah, KSA

2 Domain of Learning and Makerspaces

Traditionally, learning is seen as a vertical process where the instructor serves as both the repository and transmitter of knowledge while the practice is viewed as an application of the theory being learned. However, with the rapid development and easy access to information and communication technology, new methods of teaching and learning have been developed, particularly in engineering education where educational institutions are changing the way faculty and students learn, work, and establish collaborations [17]. The domain of learning [18–23] is based upon five approaches (Fig. 2): (i) behaviorist learning which focuses on the "what" through positive and negative reinforcement leading the learner to react to external stimulus; (ii) cognitive learning which teaches the "how" including procedures and principles, and views the learner as an organized processor of knowledge and information; (iii) constructivist learning which teaches the "why" and considers learning as a process of knowledge construction, the learner is considered active and meaning is created by the learner from the experience gained; (iv) connectivism learning emerged as a result of learners' ability to acquire and share knowledge, not only inside as per the traditional learning theories, but also outside using technology through communications, nodes and connections, and finally, (v) constructionism learning as developed by Papert et al. [12] where students learn creative ways to problem-solving and engage through creative experimentation and more hands-on projects. The constructionism learning approach is derived from the maker movement or makerspaces where learners learn effectively through making things while the role of the instructor would be a facilitator who coaches and help students attaining their own goals, produce a construction that other learners can see, improve, or criticize [14].

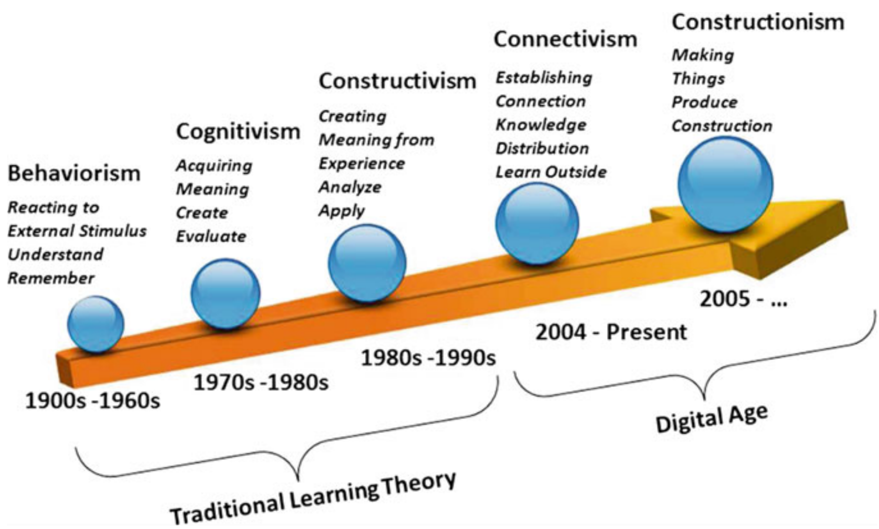

Fig. 2 Domain of learning and learning timeline

3 Knowledge Delivery for the Design Courses

Effat University is a non-profit higher education institution for women in Saudi Arabia, established in 1999, operating under the umbrella of King Faisal's Charitable Foundation. It is the first private institution of higher education for women in the Kingdom, with steady academic and aspiration for research leadership in the Kingdom. The design program of Effat University provides three fundamental academic tracks: Environmental Design, Interior Design, and Product Design. In this paper, we discuss the cases and curriculum related to the product design as they are directly related to the makers. The studio courses are structured to develop learners' knowledge and understanding from the fundamental to the advanced level where in all stages the makerspaces learning method is used and learners test ideas and develop prototypes.

The first course of product design studio 3 focuses on the development of systematic design processes through an array of different design projects, done individually and in small teams, providing discussion and illustrations of concepts, theories, terminology and methodologies of industrial design. Basic competence in shop techniques is established through the creation of simple objects and artifacts that communicate a visual narrative of value and/or function through their form. The course of product design studio 4 is based on the results of observational research, whereby students design simple, single or limited-use objects for various client groups including special populations such as children, elderly and the disabled. By limiting the complexity of the projects, the focus of the course is on the generation of products forms while developing meticulous attention to every aspect of the design process. Complete, clear, compelling design documentation and construction of multiple studies and presentation models at different scales are required.

During the journey of four academic semesters, effective semester 3, students get exposed to all of the basic skills required for product design while subsequent study studios cover disciplines like Ethnography, Human factors, Digital modeling, and Bonding. All of the design studios are delivered with a specific theme for new product development where students are constantly challenged to come up with innovative solutions. This unique environment of makerspaces integrated learning creates "experiential learning environment" [24]. When assigning the design question or problem, students use various design research methods including but not limited to ethnography.

4 Method

The objective of this research was to examine the use of makerspaces in the discipline of product design through qualitative analysis of students' experience in studio 3 and 4. The criteria of assessment focused on the concept of makerspaces. Projects were developed as a sample demonstrating the effects of makerspaces on student's comprehension and skills development. The collected data in this research allowed for observing a makerspaces' experience, demonstrating the effects of using makerspaces as teaching, educational and experiential methods. Two studies have been selected to explore students' learning and their experience while designing their projects in the FabLab. The first case involves fabrication of a bicycle, a product applicable for two users' types or generations while in the second one students were assigned to design and produce a torch applicable for two users' types or generations.

In the Design programs, studio 4 takes places in semester 4. Learners were challenged to re-design a wish bane bike. Using a number of criteria, students came up with different alternatives and solutions. This product could be developed for children under the age of 5 years on plastic scale modes as a toy. A next age group for the same concept design was proposed for children above five years of age where the product would be manufactured from sustainable materials such as wood and plastic. Studio 3 is the first level product design studio where students are taught basic methods as an introduction and then get challenged within simple products and work in makerspaces environment where they use 3D printing and digitals modeling as primary tools. Students were given the fundamentals mechanics to proceed with their design involving some mechanical engineering and technology knowledge. Viewed according to the entrepreneurship perspective of the product, a scaled size product could be produced as a toy for children to play with some modification in product features and options.

5 Results and Discussion

In order to investigate the effects of makerspaces on design studio, one group has been identified at two levels. A group of students at Effat University studied Studio 3 in spring 2017 and then Studio 4 in fall 2017, in subsequent semesters where their psychomotor skills were measured. Since the product design program is new at the university the enrolment number is below 10 students. At the time of conducting this research, there were 7 students in the group, whose results are discussed herewith. Effat University sets 60% as the passing grade for students in all programs. Figure 3 shows the grade percentage of the final project with and without makerspace. Upon analysis and comparison of the final project data, Figs. 3 and 4, in both studios, significant improvement was recorded, which can be credited to use of the Makerspaces facility in the later studio. In Fig. 3, the overall distribution shows improvement for each student, with the best student increasing score by more than 5% as a result of makerspaces.

Research and experience point to the existence of a correlation between the makerspaces environment and design education. While analyzing various factors, it emerged that in design education and other domains of education the practical skills are measured under the category of "Psychomotor Skills" which is represented by fifth domain in the National Qualifications Framework (NQF) for Higher Education in the Kingdom of Saudi Arabia [25]. According to NQF, psychomotor skills

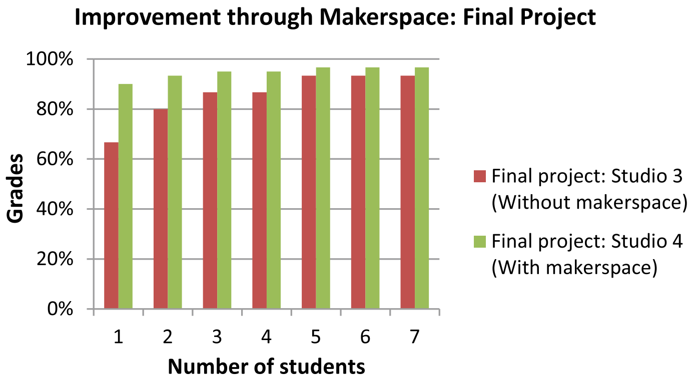

Fig. 3 Final project results for spring 2017 (studio 3) and fall 2017 (studio 4)

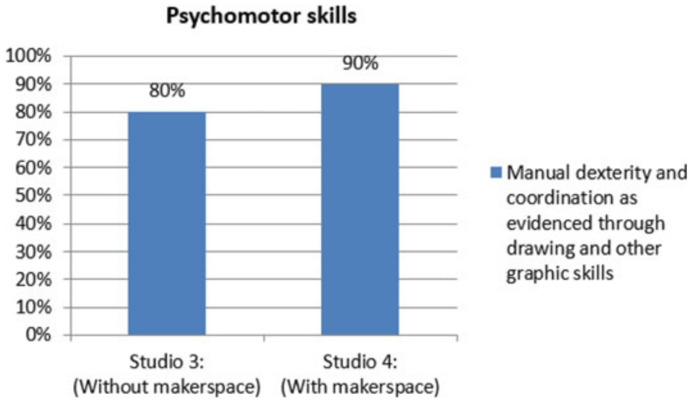

Fig. 4 Psychomotor skills in spring 2017 (studio 3) and fall 2017 (studio 4)

involve manual dexterity that is extremely important in some fields of study. Manual dexterity and coordination are evidenced through drawing and other graphic skills and also through craftsmanship which is demonstrated in the construction of study models and presentation models.

In studio 3 level, when students were assigned the task, they would use basic 3D modeling software such as 3DMax which is limited in functionality and analysis. Students, would go through the development of basic skills where sketching, manual rendering, 2D drawing, and 3D basic modeling are expected to be excelled that can be seen in the "Torch" example, contrary to Studio 4, where students develop higher level skills with Makerspaces facility, working together with other students as well as the makers community. At this level, clear evidence is seen in the form of learning and using Solidworks software, working on a complex product with a high number of variables in addition to higher basic skills, such as manual sketching and hand rendering.

6 Conclusion

Makerspaces represent open workstations for creative and collaborative learning and innovation, and sharing knowledge tools in a creative environment. Makerspaces allow students to implement their projects in a wide range of ways and help them prepare for their future profession by acquiring practical experience alongside the theoretical background. The key point here is that learning by making to produce new constructions that may be visualized, criticized or improved by others based on the theory of constructionism. Based on the course learning outcomes and psychomotor skills set initially for the product design program, this study shows that the implementation of makerspaces provides learners with opportunities to use digital product techniques and tools with three-dimensional printing, and hence improves their creativity and innovation in the design of products. Makerspace helped students turn their innovative ideas into new designs and as result further supporting the contributions to entrepreneurship and community development. Further research on the possible relations between design and 3D construction would be useful for students' learning the field of entrepreneurship in addition to exploring the accessibility of makerspace to the large community in order to provide viable opportunities of leaning by making and to sustain community development in general.

References

1. Brahimi, T., Sarirete, A.: Learning outside the classroom through MOOCs. Comput. Hum. Behav. (2015). https://doi.org/10.1016/j.chb.2015.03.013
2. National Academy of Engineering of the National Academies: Educating the engineer of 2020: adapting engineering education to the new century (2005)
3. Bates, T.: Teaching in a Digital Age, Guidelines for Designing Teaching and Learning for a Digital Age. Tony Bates Associates Ltd. (2015)
4. Duderstadt, J.J.: Engineering for a Changing World a Roadmap to the Future of Engineering Practice, Research, and Education. Millennium Project, University of Michigan (2008)
5. Anderson, V.: Makers: the New Industrial Revolution. Crown Business, New York (2012)
6. Hatch, H.: The Maker Movement Manifesto," Rules for Innovation in the New World of Crafters, Hackers, and Tinkerers, 1 ed. McGraw-Hill Education (2013)
7. Khalifa, S., Brahimi, T.: Makerspace: a novel approach to creative learning. In: Learning and Technology Conference (L&T), 2017, The MakerSpace: from Imagining to Making (2017). https://doi.org/10.1109/lt.2017.8088125
8. Van Holma, E.J.: Makerspaces and contributions to entrepreneurship. In: ScienceDirect. Elsevier Ltd. (2015)
9. Saorín, J.L., Melian-Díaz, D., Bonnet, A., Carrera, C.C., Meier, C., De La Torre-Cantero, J.: Makerspace teaching-learning environment to enhance creative competence in engineering students. In: Thinking Skills and Creativity, vol. 23, pp. 188–198. Elsevier Ltd. (2017)
10. Weinmann, J.: Makerspaces in the University Community. Master's thesis. Institute of Product Development. Technische Universität München, Germany (2014). https://web.stanford.edu/group/design_education/wikiupload/0/0a/Weinmann_Masters_Thesis.pdf
11. Fisher, E.: Makerspaces move into academic libraries. ACRL TechConnect, available at: http://acrl.ala.org/techconnect/?p¼42340 (2012). Accessed 2 Apr 2014

12. Papert, S., Harel, I.: Constructionism: Research Reports and Essays 1985–1990 by the Epistemology and Learning Research Group, the Media Lab. Massachusetts Institute of Technology, Ablex Pub. Corp, Norwood (1991)
13. Piaget, J., Inhelder, B.: The Child's Conception of Space. See especially "Systems of Reference and Horizontal-Vertical Coordinates", pp. 375–418. W. W. Norton & Co., New York (1967)
14. Martinez, S.L., Stager, G.: Invent to Learn: Making, Tinkering and Engineering in the Classroom. Kbh., Nota (2019)
15. Hlubinka, M., Dougherty, D., Thomas, P., Chang, S, Hoefer, S., Alexander, I., MccGuire, D.: Makerspace Playbook. Maker Media. Available from: http://makerspace.com/wp-content/uploads/2013/02/MakerspacePlaybook-Feb2013.pdf (2013)
16. Barrett, T., Pizzico, M.C., Levy, B., Nagel, R.: A review of university maker spaces. In: 122 ASEE Annual Conference & Exposition, June 14–17, 2015, Seattle (2015)
17. Education 2030.: Towards Inclusive and Equitable Quality Education and Lifelong Learning for All. ED-2016/WS/28, Incheon Declaration and SDG4—Education 2030 Framework for Action (2015)
18. Cohen, L.L., Manion, L., Morrison, K.: Research Methods in Education. Routledge, London (2007)
19. Will, H.: Makerspace: Towards a New Civic Infrastructure". Retrieved Jan. 2017, from https://placesjournal.org/article/makerspace-towards-anew-civic-infrastructure/
20. Sarirete, A.: Knowledge and learning issues related to engineering education: a constructivist approach. Int. J. Teach. Case Stud. **2**(1), 17–28 (2009)
21. Wenger, E.: Communities of Practice: Learning, Meaning, and Identity. Cambridge University Press. Willey, Cambridge (2013)
22. Siemens, G.: A Learning Theory for the Digital Age. Retrieved January 2017 from http://www.elearnspace.org/Articles/connectivism.htm (2005)
23. Peggy, A.E., Timothy, J.N.: Behaviorism, cognitivism, constructivism: comparing critical features from an instructional design. Perspective **6**(4), 50–72 (1993)
24. Kolb, D.A.: Experiential Learning: Experience as the Source of Learning and Development. Pearson Education, Upper Saddle River (2015)
25. https://www.ncaaa.org.sa/en/Releases/NationalQualifFrameworkDocuments/National%20Qualification%20Framework.pdf