

“Making” to the Future: An Innovative Approach to Undergraduate Science Education

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Abstract

“Making” - a hands-on practice of creating technology-based artifacts typically involves integrating electronics, programming, or 3D printing. This paper describes the targeted infusion of “making” into undergraduate STEM education as an approach to encourage innovation while building capacity in the 21st-century technical STEM skills of engineering and design. “Making” has the potential to impact self-efficacy and building capacity in technical STEM skills among underrepresented and underserved science majors. To investigate how “making” experiences are received by Underrepresented Minority (URM) students at an Historically Black College or University (HBCU), we applied and received funding through the National Science Foundation HBCU-UP Targeted Infusion Project (TIP) mechanism. The infusion included “making” instructional practices and Course-based Undergraduate Research Experiences (CUREs) into two undergraduate biology courses. Assessment data indicates the targeted - infusion courses were well-received by these communities with females excelling in iteration and communication of engineered designs.

Introduction

“Making”, as outlined by Harvard Educational Review Editorial Board, is a learning strategy that engages participants in three areas: 1.) self-directed learning, 2.) problem-solving, and 3.) collaborative work to create project artifacts [1]. This strategy provides hands-on learning experiences with digital fabrication tools, such as 3D printers, laser cutters, computer numerically controlled (CNC) machines, and digital electronics in informal learning environments. These experiences connect engineering and design competencies with technical fabrication skills to foster creative and innovative outcomes. As a result, “making” has been viewed as a promising learning approach to broaden participation in STEM and prepare students to thrive in a digital economy; however, little research exists on the integration of “making” in formal classrooms, particularly in specific content areas of higher education, such as the biological sciences. While there is significant use of 3D printing at Predominantly White Institutions (PWI) in the sciences [2], articles detailing the incorporation of “making” or 3D printing and the engineering design process into undergraduate biology courses is limited and no reports exist on infusion of “making” into a Historically Black College or Universities (HBCUs) exist [3, 4, 5, 6]. “Making” in this targeted - infusion project will involve the infusion of computer aided design (CAD) software and 3D printing principles into two formal biology classroom environments at an HBCU.

Specifically, we present assessment data that 3D “making” projects were successful in introducing undergraduate biology students to engineering design and fabrication. The ‘making’ project were incorporated into two undergraduate biological science courses which had laboratory sessions taught as Course-based Undergraduate Research Experiences (CUREs). CUREs offer authentic research experiences to undergraduates in contrast to traditional “cookbook” assignments for student learning [7]. CURE projects are relevant to the broader scientific community (beyond the context of the course) [8] and have the potential to incorporate interdisciplinary skillsets [9]. Despite the increasingly widespread application of CUREs, there are very few documented implementations within undergraduate biology courses that incorporate the engineering design process. In those few examples, the incorporation of the engineering design process or “making” in science courses has been found to increase students’ science attitudes, problem-solving skills, and scientific content performance [10].

Since HBCUs already award 40% of STEM undergraduate degrees [11], the targeted-infusion project described herein has a unique advantage in dissecting the potential of “making” to increase diversity in the 21st century. By providing ‘making’ experiences that deepen and broaden their understanding and application of interdisciplinary knowledge, underrepresented minorities (URM) will enter higher-level academic and workforce communities with expanded STEM skills.

Our innovative approach to undergraduate STEM education has shown some benefits in increasing accessibility, active learning, self-efficacy, and creative innovations among undergraduate students. We report that “making” in the context of CURE-infused biology courses was well-received by URM students with a modest gain in positive attitudes about abilities to ‘do well in science’. In particular, we report on female students out-performing male counterparts in this engineering-related skill of “making”.

Course Structure: Methodology

“Making” was infused into two courses using the Course-based Undergraduate Research Experiences (CUREs) model; 1.) a BIOL2030 called Drosophila Behavioural Genetics (DaBuGs) (sophomore-level, honors, elective) and 2.) a BIOL3100 Genetics required course (1st semester junior-level). The CUREs learning strategy provides undergraduates with authentic laboratory research experiences in determining the genetic susceptibility of *Drosophila* to ethanol-induced behavior of sedation [5, 6]. The laboratory component of both courses was infused with “making” to varying degrees of complexity based on course-time allotment to digital fabrication. As a result, two different pedagogies were used as a strategy to infuse “making” into formal classroom settings. Despite the differences in course integration and the complexity of design projects, both courses used web-based computer-aided design (CAD) software from the Autodesk Design Suite called TinkerCAD for their design projects.

In the junior-level course required for biological science majors, BIOL3100 Genetics, students must design a 3D model to illustrate a molecular or phenotypic representation of an inheritable family trait during a semester-long project called Genetics of Me (GOM). “Making” was infused into the course using informal learning approaches with tutorial videos providing self-directed, self-paced learning in CAD software. Cross-curricula instruction facilitates on-demand

technical support during the course laboratory, either in-person or virtually, at scheduled times at the student's discretion. Following the TinkerCAD orientation, these informal instructor meetings facilitate the student's progression through the engineering process from brainstorming to creating a 3D model with feedback and technical support. The completed CAD file is exported from TinkerCAD as a stereolithography (stl) file and submitted to the instructor for printing. The final 3D artifact is printed and made available to students for post-processing and inclusion in their GOM oral presentation for scoring according to a rubric (Table 1).

In the sophomore-level course offered as a biology honors elective, BIOL2030, *Drosophila* Behavioural Genetics (DaBuGs), students designed and fabricated prototypes to improve the efficiency of the *Drosophila* Ethanol Mobility Assay (EMBA) or to solve a real-world research problem related to the handling and observing of flies undergoing the EMBA. In addition to an instructor-led orientation to EMBA, students were provided with a formal instructor-led introduction to the design-thinking processes used for project development and the workflow from CAD to computer aided machining (CAM) using 3D printers. The instructor-led CAM training involved the use of slicing software and setting of printing parameters such as infill, supports, and adhesion. Additionally, students learned to calibrate the 3D printer, including bed leveling and filament loading. Although students were introduced to CAM during formal laboratory settings, the learning of CAD and CAD design occurred during informal learning settings with self-directed usage of tutorial videos provided by Autodesk and the course instructor. Student projects are developed through a series of subsequently scheduled formal project meetings throughout the design-thinking process involving the instructor and other students to discuss design iteration, design challenges, and user feedback

Recruitment

At NCCU, the mission is to educate and train African Americans for global careers in the 21st Century [12]. Our current course demographics (81% black, 6% white and 4% Latin-X) reflect that we are participating in this mission to date. The students participating in the “Making”-infused CURE (DaBuGs) and CURE-like (Genetics) courses are predominantly from underrepresented minority groups. The combined course demographics are shown in Figure 1. The majority student gender in the infused courses is female (Figure 1A) and the majority ethnicity is black (Figure 1B). Therefore, active

recruitment of underrepresented minorities was not necessary. However, for the BIOL2030 DaBuGs Honors Elective course, grant P.I.s visited 1000- and 2000-level Biology courses and the Annual Summer Internship recruitment event to recruit students with a ‘B’ or better in their 1000-level courses to enroll in the elective CURE course. The paid summer internship and the resume-building, regional trips to present at annual NC Science and/or Creativity Symposiums (SNCURCS) and NC Academy of Science (NCAS) meetings were used as incentives for recruiting for the elective course.

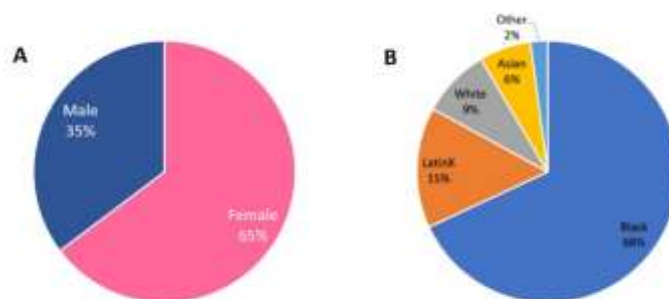


Figure 1. The demographics of the maker-infused CURE and CURE-like Biology courses at NCCU are majority female and majority black.

Course Assessments

Assessments to measure student outcomes in these targeted infused courses included both formative and summative assessments. Formative assessments of the targeted infused courses included regularly scheduled project meetings called “Lightning Talks” where students present their 3D model to display their status for peer and instructor feedback on design aesthetics and challenges with 3D printing. Lightning Talks served as the iteration process to infuse the engineering process and design thinking methodology. This approach provides an opportunity for instructors to facilitate personalized CAD instruction, ensure comprehensibility of their 3D design, and for students to refine their model for presentation. Various summative assessments were used for the targeted-infusion courses, including diagnostic assessments, feedback surveys, focus groups, and artifacts based on the course structure. Both infused courses completed the CURE pre-test and post-test diagnostic assessment to measure student experience (modified from reference [13]). In addition, both courses completed a “making” post-survey to measure the impact of “making” on student outcomes. Students were asked open-ended questions to reflect upon their experience. BIOL3100 Genetics included a summative oral presentation, Genetics of Me (GOM), which involved presenting a 3D model related to the student family genetic tree. In contrast, the BIOL2030 DaBuGs course included a design project to make a functional, behavior-measuring, 3D model. Both 3D projects were assessed using the “maker” rubric (Table 1.). The rubric measures the degree of progress each student has made using TinkerCAD and 3D printing by assessing 5 qualities: creativity, initiative, iteration, learning, and community. The degree of progress is ranked from 1 (Emerging skills) to 4 (Exemplary).

Table 1. 3-D “Maker” Design Project Rubric				
	Emerging-1	Developing-2	Proficient-3	Exemplary-4
Creativity	Student follows a set of directions to complete the project but did not explore new ways to alter the idea.	Student design project is original but mostly based off an existing model.	Student project is explored and expressed in a fairly original way	Student clearly explored and expressed multiple ideas in a unique way.
Iteration	Student does not attempt to iterate or make any changes on their initial design.	Student attempts to make an iteration on the design and/or aesthetic of their project, but is unsuccessful in any improvement.	Student undertakes 1 or more iterations of their project, improving the design and/or aesthetics.	Student completes the project, having improved the design and/or aesthetics over time.

Initiative	Student encounters complications with frustration and does not attempt to problem solve.	Student encounters complications with frustration, but attempts to problem solve before seeking assistance.	Student encounters complications with a positive attitude and attempts to problem solve before seeking assistance.	Student encounters complications with a positive attitude and attempts to problem solve without seeking assistance.
Learning	Student did not attempt any new learning or methodology they were not already comfortable with.	Student attempted 1 new avenue of learning for their project but may not have been successful in its implementation.	Student attempts 1 new avenue of learning for their project. They demonstrate a skill they did not have at the start of the project.	Student attempts multiple new avenues of learning for their project. They demonstrate a skill they did not have at the start of the project.
Community	Student does not share their learning	Student attempts to share their learning but without adequate explanation or reflection.	Student shares their learning informally in a peer-to peer fashion.	Student shares their project and learning in a formal manner

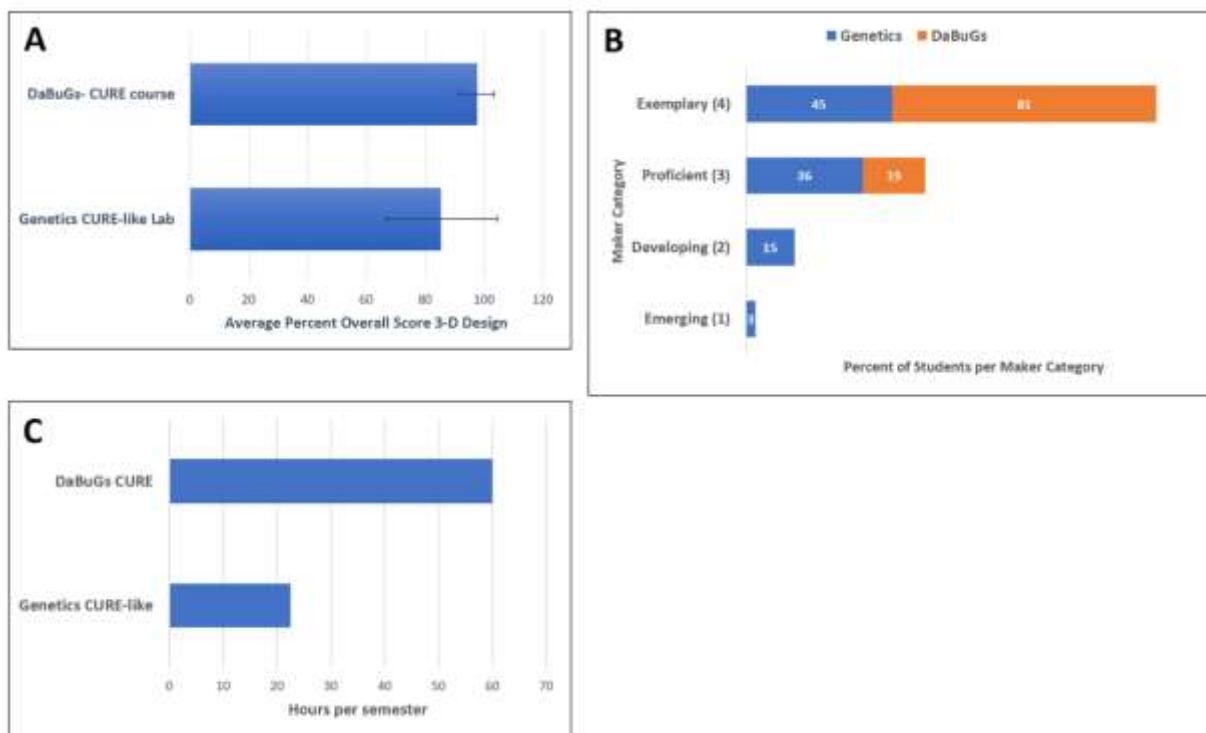


Fig 2. Results of 3D Assessment indicate differences in DaBuGs and Genetics student progress which may reflect time given to project per course. A.) Average overall score in percentage; B.) percent students achieving each of 4 levels of achievement; C.) hours spent during semester on project.

Results

The summative assessment for these courses involves a formal oral presentation at the semester's end to present their 3D model by in-person or virtual presentation. The 3D models are graded by the "Maker" Design Project rubric (Table 1.). A comparison of students in BIOL2030 DaBuGs (elective) and BIOL3100 Genetic (required course) indicates students in BIOL2030 performed significantly better (98%; $p = 0.0004$ on the Summative 3D Maker Assessment than students in the Genetics course (85% average score) (Figure 2A). Comparison of DaBuGs and Genetics students results indicate that the average overall score was at least 80% (Genetics) or 98% (DaBuGs). In fact, 45% of participating Genetics students achieved an 'exemplary' level of engineering design skills. In contrast, in the newly developed, fully infused DaBuGs Honors CURE course, 81% of students met the 'Exemplary' rating (a rating of 4 out of 4 in all five categories). Additionally, the rest of the DaBuGs students (19%) and 36% of Genetics students earned the second highest achievement rating of "Proficient" (students must score at least '3' in each of the five categories) (Figure 2B). The comparison of student scores between the two classes supports previously reported assertions that students spending more time engaged in a CURE or CURE-like project achieve higher gains [14]. Figure 2C illustrates that students enrolled in the BIOL2030 DaBuGs sophomore-level, honors elective course spent 3x more time focused on their research and design project than students enrolled in the BIOL3100 Genetics required course. While we cannot eliminate other variables including

class size and the need to study required curricular materials that impact student success, time spent was certainly a notable difference (Figure 2C). However, through the required Genetics course ($n=33$; DaBuGs $n=14$), we were able to expose at least 2x more students to ‘making’ techniques that they had not previously experienced.

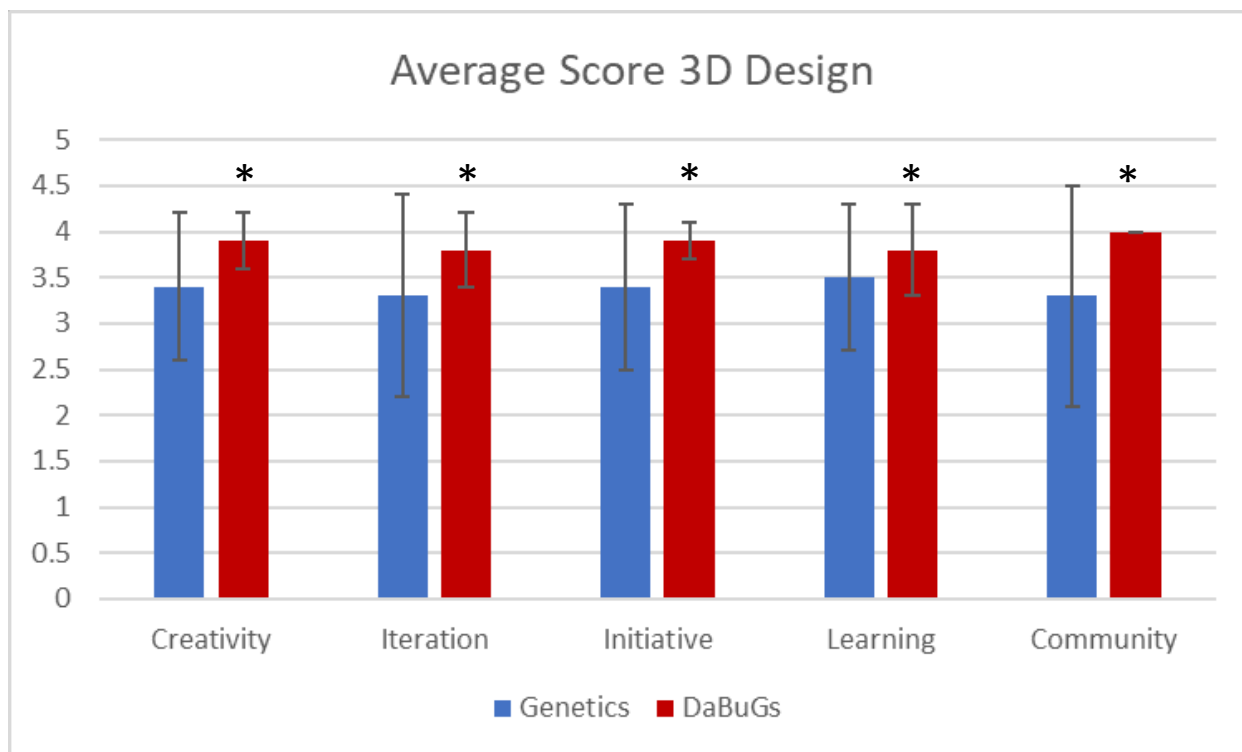


Figure 3. Average scores of summative Maker assessment divided into 5 categories. DaBuGs students have significantly higher means than Genetics students (all p values < 0.05).

Separating the 3D Design rubric into the 5 elements of “Maker” rubric is shown in Figure 3. At first glance, it appears that the two areas that DaBuGs students excelled in are 1.) the ‘Iteration’ category in which students were rated for the number of times they attempted to improve their “making” projects; and 2.) the ‘Community’ category which gauges how effectively they communicated their ‘making’ projects to their classroom community. However, T-test comparisons of each category reveal that all categories are significantly different with P values below 0.01 for all categories except the ‘Learning’ category which had a P value of 0.03. Also of note, is the standard deviation from the mean which is much larger in the Genetics infused lab (required for all Bio majors) compared to the DaBuGs infused course (honors elective). This large degree of variance could be due to class size differences and/or the amount of time spent on their “making” projects (Figure 2C). Overall, most students in the CURE-like Genetic and CURE DaBuGs courses achieved a level of at least ‘Proficient’ or better in engineering design in fabrication amongst Biology majors populated by underrepresented minorities.

The quantitative post-assessments for the CURE and “making”-infused targeted-infused biology courses indicates that students approve of this innovative education approach, with over 90% in agreement that the combined courses were ‘good’ formats for learning the subject matter and/or

the scientific research process (Figure 4: 2nd and 4th Evaluation Criteria). Additionally, 79.2% of students agreed that the courses had a positive effect on their attitude in science (Figure 4: 3rd of 4 Evaluation Criteria).

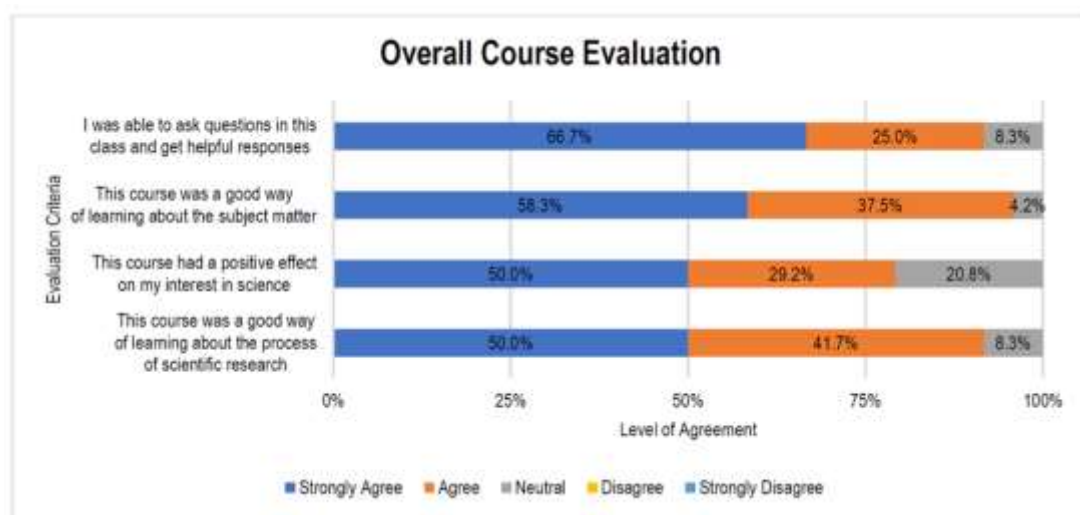


Figure 4. Overall course evaluation per external evaluator analysis of pre-/post-CURE Surveys.

Overall, students were confident about their ability to ‘do science well’ (Table 2). Using a 5-point Likert scale, students rated their attitudes about ‘doing science’, with 5 meaning ‘strongly agree’ and 4 meaning ‘agree’. Comparison of the CURE Pre-test score (4.13) and post-test score (4.33) show there was an increase in confidence; however, the mean difference between pre-test and post-test scores is not statistically significant with ANOVA value of $p=0.426$ (Table 2). When comparing the Genetics group to the DaBuGs group, 90% of Genetics and 88.3% of DaBuGs students agreed at pre-survey; and 92.9% of Genetics and 80% of DaBuGs at post-survey. Therefore, while there was an increase in confidence among Genetics students, there was a slight decline in confidence among DaBuGs students.

Notably, the pre-/post-Survey data was gathered in Spring 2020 and Fall 2020, in which the Covid-19 pandemic significantly impacted the ability to do ‘hands-on’ laboratory work for a larger proportion of the DaBuGs students (Spring 2020), than the Genetics students (surveyed in Fall 2020). Thus, when hands-on laboratories continued to the end of the semester (Genetics), the post-survey indicated increases in STEM confidence level.

Table 2. Pre-/Post-Assessment for attitudinal item “I can do well in science”

Time	Mean	N*	Std. Deviation
Pre-course	4.13	15	0.834
Post-course	4.33	24	0.834
Total	4.26	39	0.751

* pre-/post-CURE Survey data collected Spring and Fall 2020

Pre-/post-Assessment Data Revealed Mixed Demographic Results

The post-CURE Survey indicated that female attitudes improved post-course. Post-course survey results show that 64.3% of females strongly agreed with the statement: “I can do well in science” ($M=4.64$, $SD=.50$) compared to 33.3% at pre-survey ($M=3.90$, $SD=.74$). Conversely, attitudes among males decreased slightly on the post-course survey compared to the pre-survey. At pre-survey, 33.3% of males strongly agreed that “I can do well in science” ($M=4.17$, $SD=.75$), however, at the end of the course, only 20% of males strongly agreed ($M=4.11$, $SD=.93$). Unfortunately, black students’ attitudes at pre-survey ($M=4.5$, $SD=.548$) decreased at post-survey ($M=4.27$, $SD=.79$) or (100% at pre-survey compared to 81.9% at post-survey). While the quantitative survey data is disheartening for males and Blacks/African Americans, it is important to keep in mind that the current pre-/post-Survey data was gathered during the first year of the pandemic when a lot of hands-on time with “making” and CURE research projects was lost. Indeed, students did note that loss of ‘hands-on’ time impacted their experience. Thus, it is all the more impressive that despite the pandemic challenge, overall female attitudes improved by approximately a factor of 2. Therefore, the approach is facilitating the confidence level of one of our targeted underrepresented groups: females.

Qualitative Post-“Making” Reflection Survey

Upon conclusion of their semester-long “Maker” Project, students were asked to reflect upon their experience. In response to the following open-ended question, students responded that the

Table 3. Selected Student Responses to prompt: “What skills, behavior or attitude did the 3D design project influence in regard to your learning and/or competency?” “It influenced my creativity when it came to problem solving as well as presenting.” “The 3D design project allowed me to understand breaking things up in pieces to fully conquer a project. Also, to accept the fact that not everything turns out right the first time.” “Creativity and some thinking as how the finished model could help convey an idea.” “Creativity, time management, It made me think about my chosen subject more.” “It provided a connection between science and art. 3D printers have played an influential role in developing and studying science. By providing a 3D handheld model to study and use”

3D Maker Project impacted their ability to problem-solve, think critically, think creatively, and realize that creating 3D artifacts takes time (Table 3). Additionally, as the last student comment suggests, students can make the connection between science and art. Thus, the 3D project encourages students to use higher-order thinking skills to convey abstract ideas in corporeal form.

Ethnicity comparisons using 3D Maker Assessment Rubric

Since North Carolina Central University (NCCU) is a Historically Black College or University (HBCU) with ~80% of its student population being classified as Black/African American/African, students of other ethnic groups are the rarity. Thus, when breaking down the assessment results into demographics, the majority group is Black/African-American and the other ethnicities (White, Asians, LatinX/Hispanics) are grouped together under the ‘ALL Others’ category in this section of our report. The number of non-repeating Genetics students that were enrolled in the Genetics lab for Fall 2020, Spring 2021 and Summer 2021 and participated in the Genetics of Me/’making’ project were 33 in number. The demographics of the Genetics (BIOL3100) course infused with “making” projects is distributed as follows:

73% Black/African-American/African, 15% white, 9% Latinx. Thus, the majority of students in the CURE-like, “making”-infused Genetics lab are black. Out of a total of 20 points, the overall average score for black versus ‘all other’ ethnicities of students is 17.2 versus 17.9, respectively. T test analysis confirms that the differences in overall score are not significant ($p=0.26$). Therefore, the black underrepresented minority (URM) group performs equally well on the overall ‘making’ project as other ethnic groups.

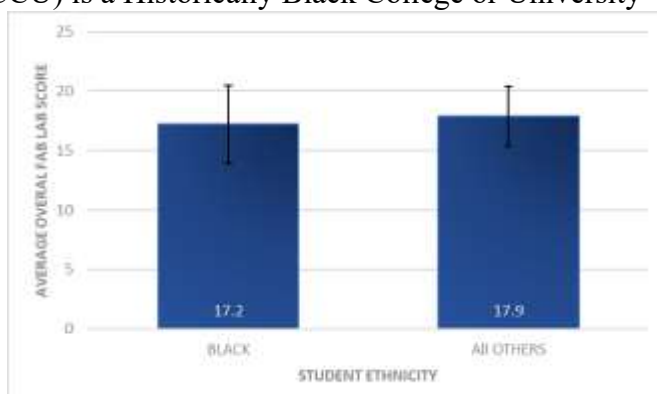


Figure 5. Average scores indicate that NCCU GENETICS (BIOL3100) students perform equally well on the summative ‘making’ project regardless of ethnicity. Three semesters worth of students (F2020, S2021 & Su2021) participated in the Fab Lab-infused Genetics of Me project (N=33). No significant difference detected between black and other student ethnicities using a student t test ($p = 0.26$).

Breaking the “making” project down into the 5 categories and comparing black to ‘all other’ students suggests that both groups perform equally well in most categories with no significant differences in “making” performance (Figure 6).

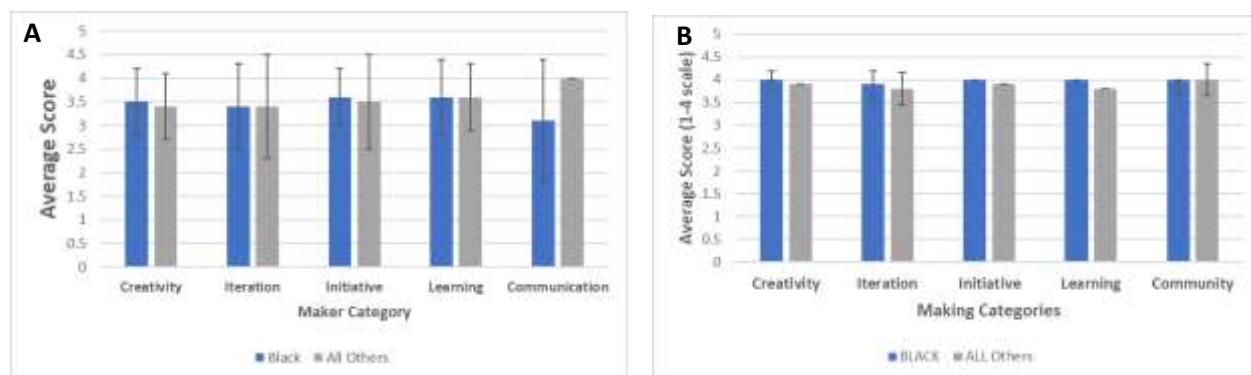


Figure 6. Black and all other ethnic students perform equally well in most maker categories in maker-infused courses. Summative data collected from three semesters of

students (F2020, S2021 & Su2021. Panel A.) Genetics students. All p values are greater than 0.05 except in the communication category ($p = 0.002$). B) DaBuGs students. T tests indicate no significant differences in average scores between student groups (all p values < 0.05).

Gender Comparison

Females are an underrepresented group in Engineering. To determine if females in the two courses accomplish “making” gains, data was sorted by gender and analyzed. No significant difference in female and male performance in the DaBuGs CURE, nor between females and males in the Genetics CURE-like course were evident (Figure 7A). Rather, significant differences are course-dependent with students in DaBuGs performing better than females in the Genetics course ($p=0.003$) and similar results observed when comparing male DaBuGs to male Genetics students ($p= 0.04$).

When gender sorted scores are separated by category in the BIOL3100 Genetics course, the single category showing a significant difference was ‘Community’ where females earned an average score of 3.6 ± 0.5 compared to males whose average score was 2.6 ± 1.6 (Figure 7B). “Community” in terms of rubric evaluation is defined as the process of communicating their journey of designing, trouble-shooting, and presenting their final 3D model. Communicating science is an invaluable component of the scientific process; and our data illustrate this target infusion approach may build capacity in this area.

Turning attention to gender comparisons in the BIOL2030 DaBuGs course, males and females both score a perfect ‘4’ in the ‘Community’ category (Figure 7C, ‘Community’ category). This course approach included more opportunities for developing communication skills through formative assessments: 3-5 “making”-specific Lightning Talks spread throughout the semester. However, there is a significant difference in the number of times male and female students attempt to refine their *Drosophila* behavior-measuring devices, with the male average “Iteration” scores of 2.8 ± 0.5 compared to females, 4 ± 0 (Figure 7C, ‘Iteration’ category).

Therefore, in the DaBuGs CURE course, females excel in the ‘Iteration’ or trouble-shooting category.

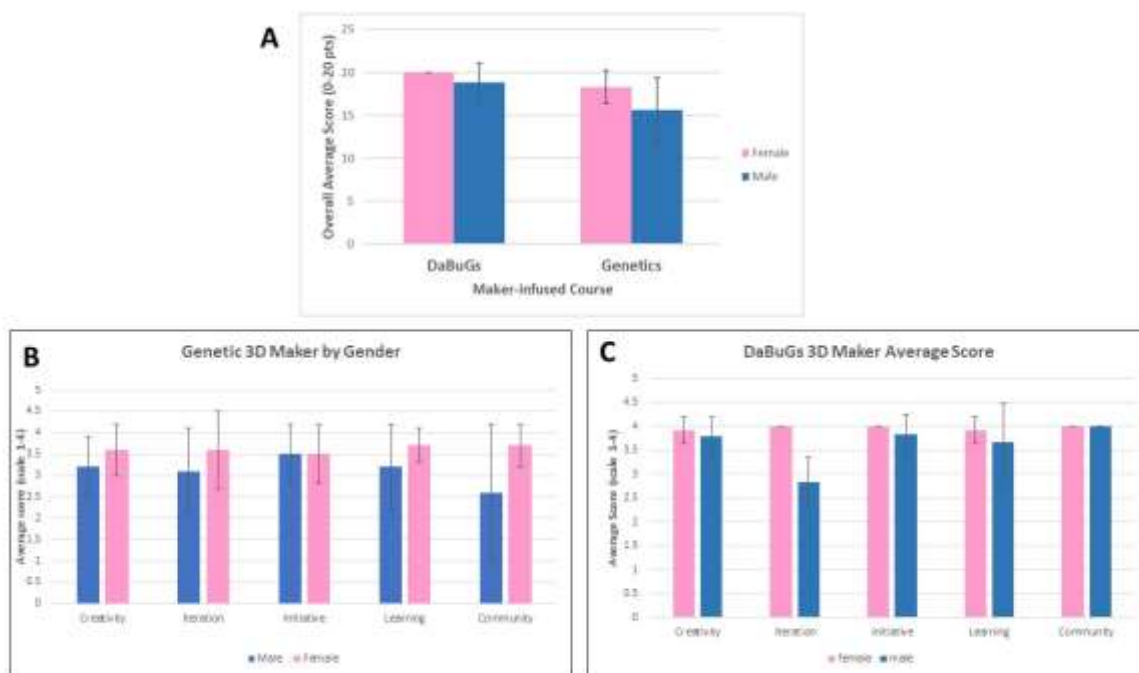


Figure 7. 3D Maker Assessment score sorted by gender DaBuGs CURE and Genetics CURE-like courses. A.) Overall scores on a scale from 1-20 points. B.) Genetics average score sorted by category; C.) DaBuGs average scores sorted by category.

Student CAD Designs

The design project for each course varied according to course objectives as described in the “Methodology” section of this paper. Figure 8 shows CAD designs representative of those created for BIOL3100 Genetics. These designs show various aspects of inheritable traits, including gene network connections, protein structure, disease therapies, wild-type and mutant comparisons (kidney), cell membrane receptor reactions, and relation of molecular to visible phenotype (Figure 8).

Figure 9 showcases designs created in BIOL2030 for usage in the *Drosophila* research assay. The



Figure 8. Student-designed artifacts in the BIOL3100 Genetics 3D Maker-infused course. These design show various aspects of inheritable traits, including A.) gene network connections, B.) protein structure, C.) disease therapies, D.) wild-type and mutant comparisons (kidney), E.) cell membrane receptor reactions, and F.) relation of molecular to visible phenotype.

devices (Figure 9; panels B-D) and apparatus (Figure 9A) were based on personal evaluations and group discussion on challenges and obstacles experienced while conducting a *Drosophila* research assay. The devices primarily involved improving the assay efficiency by reducing or eliminating human contact and manipulation in the assay. There was also considerable effort

given to improving mechanisms to transfer *Drosophila* during sorting and testing.

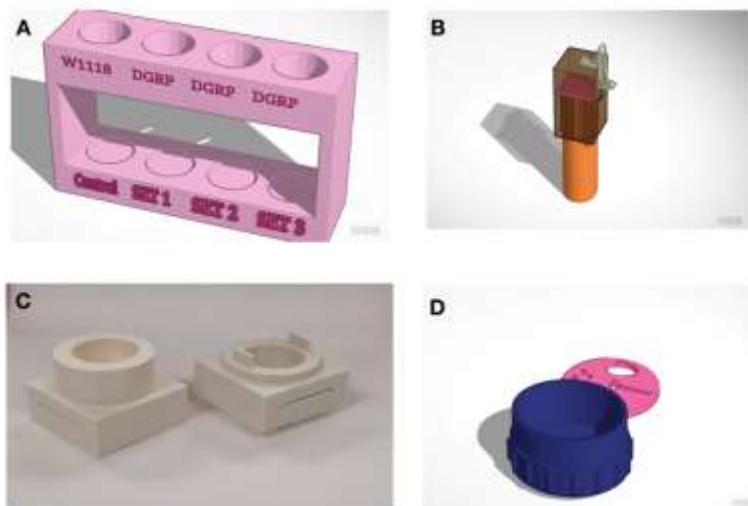


Figure 9. Student-designed artifacts in the BIOL2030 DaBuGs 3D Maker-infused course.

Discussion and Conclusions:

Overall, the “making”- infused biology courses appear to be well received by students, with over 90% in agreement that the combined courses were ‘good’ formats for learning the subject matter and/or the scientific research process (Figure 4). Additionally, although not significant, there was an increase in the overall pre-/post-assessment mean of students agreeing with the statement “I can do well in science” (Table 2). Since the students enrolled in both BIOL2030 DaBuGs and BIOL3100 Genetics were STEM majors (predominantly Biology, but also Pharmaceutical Science and Chemistry majors), it is likely that they entered the courses with positive attitudes about their ability to ‘do well in science’; thus, significant gains in confidence were high upon entering the course (pre-test results, Table 2). It is notable that each course was infused with engineering design and creativity, two competencies unfamiliar to biology courses, however the targeted-infusion did not adversely affect overall attitudes. Indeed, a majority of students responded that the courses were “good” formats for learning science. Additionally, as the last student comment suggests (Table 3), the targeted-infusion of making encourages students to use higher-order thinking skills to convey abstract ideas in corporeal form. Finally, student comments in (Table 3) suggest that the “making” experience enhances their capacity to be creative, manage time and problem-solve: invaluable skills to STEM trajectories and innovations.

Most students scored at least a “proficient” level on the “maker” rubric (87% of all students, Figure 2). However, BIOL2030 students having more formal instruction and iteration time than BIOL3100 students were able to achieve an ‘exemplary’ level score (98%). The comparison of

student scores between the two classes supports previously reported assertions that students spending more time engaged in a CURE or CURE-like project achieve higher gains [14]. Figure 2C illustrates that students enrolled in the BIOL2030 spent 3x more time focused on research and design than students enrolled in the BIOL3100 course. We note here that we were unable to eliminate other variables including class size, formal coursework, (Figure 2C) and limited hands-on experiences due to COVID-19 restrictions. Despite the differences in design rubric scores for both courses, the targeted maker infusion into the required biology course, such as BIOL3100 Genetics (n=33), increased exposure to twice the number of students than the elective course BIOL2030 DaBuGs (n=12). Thus, broadening the STEM horizons of a larger number of URM students.

This targeted infusion included opportunities for developing communication skills through iterative Lightning Talks spread throughout the semester. Female students in both the BIOL2030 DaBuGs and BIOL3100 Genetics courses outperformed their male counterparts (Figure 7A) in the area of ‘Community’ (female average score of 3.6 ± 0.5 compared to the male average score of 2.6 ± 1.6 (Figure 7B). ‘Community’ in terms of rubric evaluation is defined as the process of communicating their journey of designing, troubleshooting, and presenting their final 3D model. Communicating science is an invaluable component of the scientific process; and our data illustrate this target infusion approach may build capacity in this area.

Since 68% of the assessed student population identifies as ‘black, African or African American’ at our Historically Black College or University (HBCU), we asked whether black students and all other students performed significantly different in these “making” infused courses: and they did not.

Unfortunately, while Genetics student attitudes increased on CURE pre-/post-assessment, the attitudes decreased for DaBuGs students. However, it is important to keep in mind the data was gathered during the first year of the pandemic when hands-on time with 3D printer and the CURE research project were eliminated due to restrictions. Indeed, students did note COVID-19 restrictions impacted their experience. Thus, it is all the more impressive that despite challenges of COVID-19, Black or African American students, in particularly female attitudes improved by approximately a factor of 2. Overall assessment results suggest that the targeted infusion of “making” into formal higher education STEM courses increases self-efficacy and facilitates critical and creative thinking in STEM courses among underrepresented minority students.

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