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Bridging the Interdisciplinary Divide in the Biomedical Engineering Classroom Using Social Constructivism and Collaborative Annotations

Dr. Shreya A Raghavan, Texas A&M University

Dr. Shreya Raghavan is an Associate Professor and holds the Cain Faculty Fellowship in the Department of Biomedical Engineering. She is also a Scholar in the Regional Excellence Center for Cancer at Texas A&M University. She has a PhD in Biomedical Engineering from Wake Forest University/Virginia Tech and was an NIH Postdoctoral Fellow at the University of Michigan. At Texas A&M, the Raghavan lab engineers mechanically competent microenvironments to advance our understanding of cancer and women's health. Her approaches integrate mechanobiology, biomaterials and microenvironment engineering. In the biomedical engineering classroom, Dr. Raghavan is recognized for her inclusive and accessible pedagogy by the Montague Scholars Award, and the Provost's Innovative Teaching Fellowship from Texas A&M University. Her teaching methods prioritize student success. In addition to research and teaching, Dr. Raghavan also serves the Society for Biomaterials and the Biomedical Engineering Society in various roles.

Bridging the Interdisciplinary Divide in the Biomedical Engineering Classroom Using Social Constructivism and Collaborative Annotations

Affiliation: Texas A&M University

Running Title: Learning through collaborative annotations with Microsoft Whiteboard

Keywords: peer-supported learning, social constructivism, visual explanation, inquiry-based learning, collaborative annotation, Microsoft whiteboard, biomedical engineering

ABSTRACT

Background: Biomedical Engineering (BME) requires students to integrate diverse knowledge domains in life sciences and engineering, applying different learning frameworks. The vast interdisciplinary gap in student cohorts sets up an additional challenge to learning, especially within broad and deep graduate or upper-level technical BME elective courses. The study is presented in the context of a graduate-level "Cancer Bioengineering" course, designed to bridge cancer biology with engineering discovery through interpretation of peer-reviewed scientific data.

Implementation and Assessment: The study utilized a phased pedagogical approach based on social constructivism and inquiry based learning within Cancer Bioengineering. Students were challenged with authentic tasks in the form of prompted interpretation of peer-reviewed scientific data, to co-construct comprehensive knowledge in cancer. Microsoft (MS) Whiteboard was used as a scaffolding tool to facilitate collaborative annotations of scientific data. Assessment was conducted through qualitative instructor observations of discussion depth, evaluation of student annotation quality, and anecdotal student feedback.

Results and Impact: Qualitative evidence indicated that collaborative annotations visualized student thinking by anchoring learning to a prompted task. Students with diverse backgrounds and professional experiences in BME (life sciences, engineering, industry internships, clinical immersions, wet lab research, etc.) brought their own lens towards data interpretation. Within small groups and classroom-wide, students leveraged their knowledge to synthesize scientific data and negotiate meaning within the context of cancer bioengineering.

Conclusions and Future Considerations: The study demonstrates that integrating collaborative digital annotations within a social constructivist framework effectively bridge the interdisciplinary divide in BME education. Rooted in inquiry-based learning, students with diverse expertise effectively and collectively negotiated meaning to construct a holistic understanding of how engineering approaches have transformed cancer discovery and therapeutics. Ultimately, our findings highlight that social constructivist learning environments empower BME students to synthesize complex biological data through a rigorous engineering lens.

1. Introduction

Biomedical Engineering (BME) education inherently combines two different streams: descriptive, systems-level functions in the life sciences with design-focused, quantitative functions in engineering. The breadth and depth of BME coursework in graduate or upper level technical electives is a significant stressor for students, especially considering their diverse backgrounds in life sciences and engineering [1, 2]. Students at this interdisciplinary junction require more than memorizing biological facts. They are expected to think like an engineer (apply quantitative frameworks and analyze data with a solution-centric mindset), yet operate within a biological context. The diverse backgrounds of BME cohorts, therefore, creates not just a knowledge gap, but also an engagement gap within the BME classroom. To overcome this, BME curricula have shifted to favor active, hands-on, inquiry-based and experiential design to ground learning in real-world relevance [3-5]. In this study, a phased pedagogical approach was implemented using social constructivism and inquiry-based learning, supported by collaborative annotations using Microsoft (MS) Whiteboard.

1.1 Teaching and learning context: Cancer Bioengineering

Cancer Bioengineering was designed to bridge cancer biology with engineering-based discovery and design. The course was structured into two modules: (1) Engineering approaches to promote cancer discovery; (2) Engineering approaches to treat cancer. This structure integrated engineering principles throughout, without creating silos between biology and engineering. Upon completion, students were expected to:

(i) construct and de-construct many ways cancer cells can be arranged in three-dimensional space;
(ii) integrate how tumor structure and composition influenced biological behavior and therapeutic efficiency;
(iii) appraise how bioengineering strategies modeled complex tumor microenvironments or enhanced cancer treatment outcomes;
(iv) develop and support hypotheses surrounding grand challenges in cancer[6] by integrating their learning with critical literature review.

1.2 Theoretical frameworks and their application in cancer bioengineering: social constructivism and inquiry-based learning

Social constructivism is a learning theory that suggests that knowledge is constructed actively and aided by peer interactions, rather than by passive listening [7]. These interactions allow learners to negotiate meaning and exchange knowledge, translating to deeper contextual understanding [8]. In engineering education, social constructivism is well documented in challenge-based and problem-based learning designs where students collaboratively solve authentic engineering problems by engaging in small group activities[9-11]. Best practices in instructional design include structuring small-group collaboration, an instructor that actively scaffolds and facilitates interaction, self-directed learning, and the use of tasks that are authentic to the learning context[12]. In cancer bioengineering, social constructivism is essential for interdisciplinary sensemaking, where students with diverse expertise can leverage their knowledge in engineering or biology to co-construct a comprehensive understanding of cancer.

In this course, authentic tasks for learning were provided in the form of scientific data from peer-reviewed literature. Prompted engagement with scientific data facilitated through-an inquiry-based learning model[13], guided by the positive impact of foundational research-based teaching approaches in biomedical engineering[5, 14, 15]. Inquiry-based learning shifts student to assume roles as active investigators. Working in groups of 3-4, they were prompted to contextualize the data within the biological “what” of cancer, and to further evaluate the engineering “how” (eg. comparing molecular biology assays to newer bioengineering-rooted approaches).

1.3 Collaborative annotation as a scaffolding tool

Effective design of social constructivism deploys technological tools that enable collaborative engagement with authentic tasks at hand [16]. While inquiry-based learning anchored the discussions with groups of 3-4 students, MS Whiteboard was introduced as an additional collaborative annotation tool to explicitly visualize student thinking and knowledge construction. This tool was available to students and instructors alike, as part of an enterprise subscription by the institution, and at no additional cost.

At the end of every class period, interpretation exercises converged upon students' ability to reflect upon two questions: (1) What new biological mechanism have you learned about cancer? (2) How have engineering approaches contributed to enhancing biological discovery (or therapeutic opportunity) in cancer?

This manuscript reports the design of a social constructivist environment, anchored in inquiry-based learning, and guided by collaborative annotation. Extensive qualitative evaluations and reflections by the instructor report the efficacy of such design in interdisciplinary sensemaking in the context of cancer bioengineering with the goal of improving course design.

2. Methodology

2.1 Cohort descriptions and class structure

The course consisted of 11 senior undergraduate students and 10 graduate students within the first two years of their graduate program (mixed between Biomedical Engineering, Biology and Biotechnology). Within the classroom, students sat in groups of 3-4, mixed between undergraduate and graduate students at the request of the instructor. 6 groups were formed ad-hoc during Phase 1 and maintained through Phase 4. All students brought their own devices (laptops, tablets, etc.) to assist their learning by viewing lecture material and note-taking. Each table was additionally equipped with its own screen that mirrored a classroom screen projected from the instructor's annotation-capable device.

Figure 1: Phased implementation strategy used in Cancer Bioengineering to facilitate collaborative annotations and peer-supported learning, with or without MS Whiteboard

2.2 Phased implementation of inquiry-based learning and collaborative annotations for social construction of cancer bioengineering knowledge

A phased implementation strategy was used over the course duration of 14 weeks (**Figure 1**). A rough outline of lecture mechanics is demonstrated in **Figure 2**, for how each class period was structured.

In Phase 1, the course, syllabus, assessment and expectations were laid out to students. All students were informed of the intention to use MS Whiteboard to facilitate collaborative learning in Phases 3-4 of the course. Students were familiarized with inquiry based learning by outlining best practices for interpreting scientific data, with continued clarifications for expectations of engagement with learning objectives over the first three weeks. All data interpretation exercises were prompted, with instructor-provided guidance towards the biological context. Phase 1 primarily introduced inquiry-based learning to students, with the expectation that they will interpret real-world scientific data and construct knowledge from it. Artificial intelligence use was discouraged within the course at its initial offering.

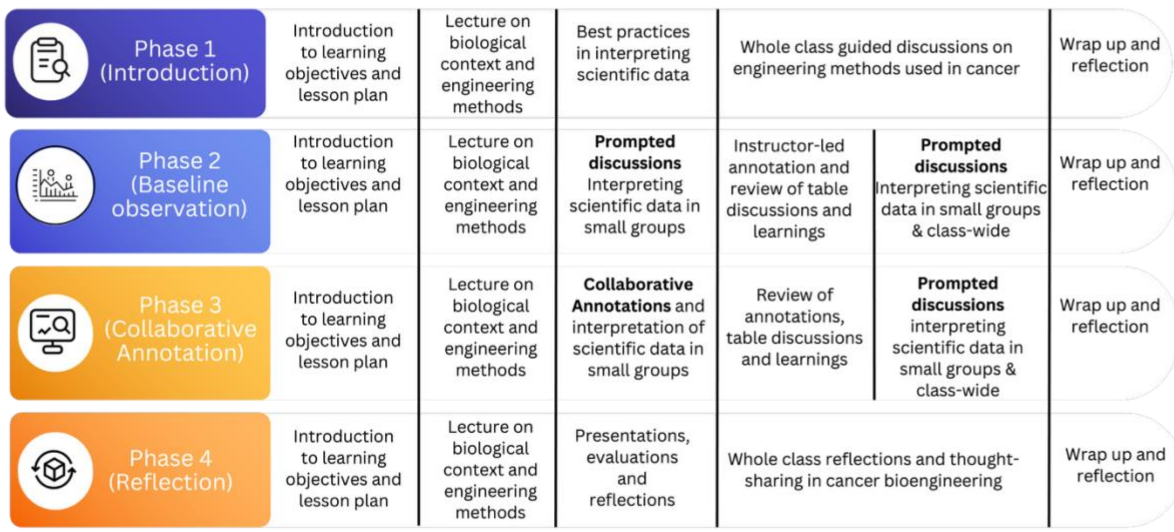

Figure 2: Structure of class periods across the phases spanning introduction (Phase 1), baseline during inquiry-based learning and knowledge construction (Phase 2), collaborative annotation during inquiry-based learning and knowledge construction (Phase 3) and reflections and evaluations (Phase 4).

In Phase 2, from weeks 4-7, inquiry-based learning continued with prompted inquiry-based learning after a 15 minute introductory lecture. Students were actively encouraged to construct knowledge within their tables related to a cancer bioengineering concept, further guided by instructor prompting when necessary. Small-group data interpretation typically took place for ~15-20 minutes, followed by a whole class interpretation via instructor annotation and discussion for an additional 10-15 minutes. While annotation best practices were not explicitly defined, they were modeled. Following small group discussions, the instructor gathered the class for a whole-class review of the scientific data in inquiry: during this time, the instructor annotated the scientific data including identifying visual trends in data, noting short phrases that represent the results from the data being analyzed or interpreted. Whole-class review and discussion was used as a method for students to construct knowledge pertinent to cancer bioengineering together. During small-group discussions, instructor actively supported each table, collecting baseline information noting the frequency, relevance and depth of discussions (defined further in detail below).

In Phase 3, from weeks 9-12 MS Whiteboard was introduced as a tool to facilitate collaborative annotations during scientific data interpretation. As a preparatory primer, students were introduced to the basic functionalities of MS Whiteboard, ahead of its use in group activities. The shared whiteboard was embedded within lecture slides that all students had access to. Within each lecture, during the designated inquiry-based learning period, students were prompted to collaboratively annotate the visuals in addition to interpreting the scientific data for ~15-20 minutes. Prompts were provided to guide data interpretation. The instructor continued to monitor discussions across all groups, guiding groups towards critically thinking about the data presented to them. The instructor also managed group participation, challenging individual students to add their perspectives on the problem at hand, thereby ensuring that all students actively participated in inquiry. An example of how a class period was divided in time during Phase 3 is demonstrated in **Figure 3**, identifying when students collaboratively annotated and pieced together knowledge first at their own tables, and then negotiated nuances in engineering methods used to study/treat cancer and debated broader approaches class-wide.

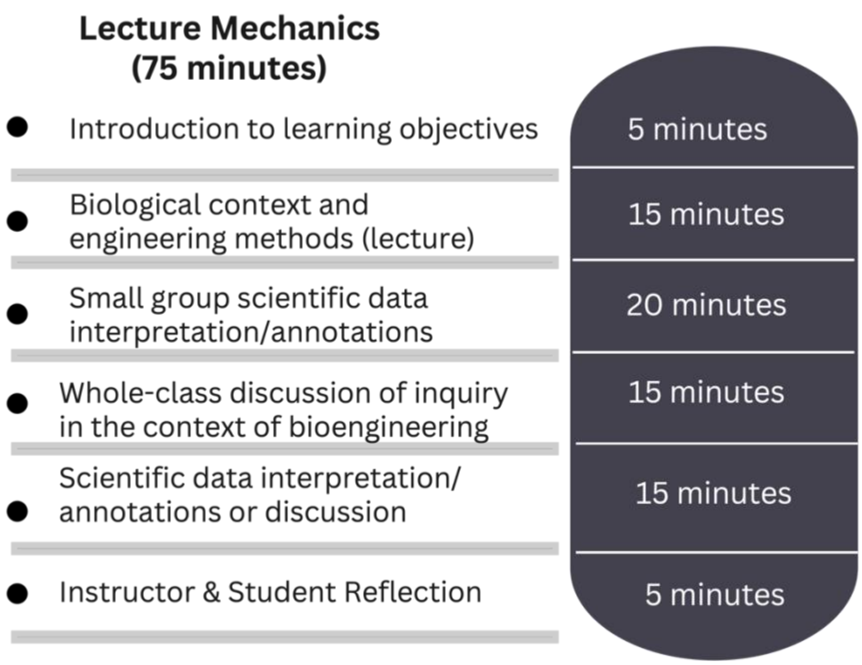

Figure 3: Division of an average class period during Phase 3 when collaborative annotations were implemented demonstrating a lecture to introduce biological and engineering context, followed by active inquiry and social construction via collaborative annotations, class-wide discussions to negotiate nuances in bioengineering.

In Phase 4, instructor led in-class reflections, collected any feedback students provided about the course including its use of MS Whiteboard for interpretation of visual data. Instructor notes from discussion observations were supplemented by their own reflections on the effectiveness of the using inquiry-based learning to socially construct knowledge in cancer bioengineering.

2.3 Evaluation of student table discussion quality and depth in the context of social constructivist learning

During prompted data interpretation exercises in Phase 2 and 3, the instructor visited each table, to listen in on their discussions, to guide students when needed and to gauge their efforts at understanding data presented to them in visual form. Discussion quality and depth were defined based on instructor notes and reflections from the end of each class. These were as follows:

i) Adequate discussion: students correctly identified trends in the data that was provided and arrived at a definitive conclusion for how engineering was used to study/treat cancer. Students collaborated to identify different aspects of data, where some were proficient at interpreting bar charts or other quantitative data, while some others were proficient at interpreting other visually rich data like microscopy images. Together, students within groups came together to construct new knowledge on how an engineering approach was used to treat or model cancer.

ii) Good discussion: building on adequate discussions, students additionally negotiated the limitations of conventional discovery or therapeutic approaches, indicating depth beyond the direct conclusions from presented data.

iii) Excellent discussion: building upon good discussions, students demonstrated increased curiosity in biological mechanisms related to cancer, finding other ways they have been traditionally studied or treated, and constructing a broader realm of knowledge than what was presented within the data. Some students were proficient in wet lab research, and contributed knowledge towards bioengineering approaches used, while some students were proficient in industry-related application spaces (like quality assurance, biomanufacturing, etc.) and contributed perspectives towards therapeutics. Overall, an excellent discussion integrated diverse notes around the focal point of the data interpretation presented, increasing not just the depth of current inquiry, but also breadth.

2.4 Evaluation of annotation quality in the context of social constructivist learning

The instructor modeled high quality annotations and encouraged discussions during inquiry-based learning sessions in Phase 2 as a primer to students annotating images on their own. MS Whiteboard was introduced as a tool for students to collaboratively annotate scientific data in Phase 3, with prompts to guide their learning and discussion. The instructor continued to note discussion depth and quality during collaborative annotations. Class-wide discussions following collaborative annotations also reviewed student annotations to piece together different perspectives on scientific data to seal learning. Additionally, in Phase 4, the instructor reviewed all Whiteboard annotations for quality. 4 annotation sets were reviewed for each of the 6 student groups, noting the frequency and nature of annotations and classified as follows:

i) Low-medium quality annotations: at least one student from the group annotated a visual trend in the data presented, but made minimal markings (circles, arrows, other pointers, emphasis) or conclusive phrases from data interpretation.

ii) High quality annotations: more than one student from the group annotated multiple visual trends in the data presented with multiple markings; students annotated conclusive phrases from data interpretation; some students applied their own perspectives on the data being interpreted adding their own visuals.

Illustrations of prompted and annotated work is demonstrated within results, to note the differences in quality. Annotation quality data is additionally reported quantitatively as % of low-medium and high quality annotations across all 6 groups, over 4 weeks.

2.5 Assessment goals and methods

The primary goals of assessment were to evaluate if collaborative annotations were an effective tool for social construction of knowledge in an interdisciplinary course like cancer bioengineering. Since instructor scaffolding is essential in social constructivist learning not just to promote discovery but also to challenge solutions and manage group contributions, the reported results and impact are heavily guided and informed by qualitative observations from the instructor. The long-term goal of these instructor-based assessments is to ultimately refine and improve the course in future re-offerings with further grounding in social constructivism via collaborative annotations.

In the context of social constructivism of cancer bioengineering knowledge, assessments are reported in three different ways:

(1) Instructor observations and notes to compare discussion quality in Phases 2 and 3 (before and during collaborative annotations; as described in Section 2.3), carefully noting different student perceptions and contributions towards prompted work, its outcome on collective reorganization of thought within student groups and class-wide, and challenging students to predict next steps or tackle broader cancer challenges.

(2) Instructor evaluation of the quality of collaborative annotations in student work across the 4 weeks of implementation in Phase 3 (described in Section 2.4), noting multiple contributions related to the learning prompt, as well as, additional independent student perspectives that contributed to constructing knowledge focused on biological context. Together with instructor observations on discussion quality, the manuscript reports reflections on how inquiry-based learning supplemented with collaborative annotations contributed positively to social constructivism, where students went beyond accumulating facts about cancer to applying bioengineering to study/treat cancer.

(3) In Phase 4, instructor evaluation of annotation quality coupled with observations on discussion quality were reviewed in the context of social constructivism in the interdisciplinary cancer bioengineering classroom. Instructor also noted anecdotal student feedback on the use of MS Whiteboard, and collaborative annotations and the ability of students to engage with each other in inquiry-based learning settings. These are aggregated and presented under the “Lessons learned” section. Reflections for instructors were also led by the Center for Teaching Excellence at Texas A&M University, among 6 fellows of the Innovative Teaching Fellowship Program run by the Office of the Provost, specific to deployment of classroom technologies for instruction.

2.6 Ethics statement

This is an observational study that does not use data from humans and does not meet the definition of human subjects research. Therefore IRB review is not required.

3. Results and Impact

3.1 Introduction of inquiry-based learning was accompanied by initial hesitancy requiring instructor-mediated scaffolding

In the initial phases of implementation (Phases 1 and 2), introduction of inquiry-based learning was met with mild hesitation in student participants, especially in the first few weeks. Hesitation looked like a lack of participation at table discussions with silent processing of guided prompts for over 10 minutes without any verbal interactions. This was unsurprising, since the introduction of inquiry-based learning can impose high cognitive load on learners, requiring instructor mediated scaffolding [17]. An example of a prompted discussion is provided in **Figure 4**, with an illustration of visual scientific data that were presented. Regardless, learning was guided through visual cues and visual integration of information[18]. Instructor-led modeling of data interpretation provided the necessary scaffolding to transition students from a telling-listening relationship to active investigators. The introduction of these prompted discussions with scientific data created a joint problem space that became a focal point of table and class-room wide discussions. Students were allowed to discuss the data and its implications for ~15 minutes, whereby the instructor listened in on table discussions noting quality and depth. With guidance and encouragement from the instructor, many students discussed within their tables to interpret the data presented to them.

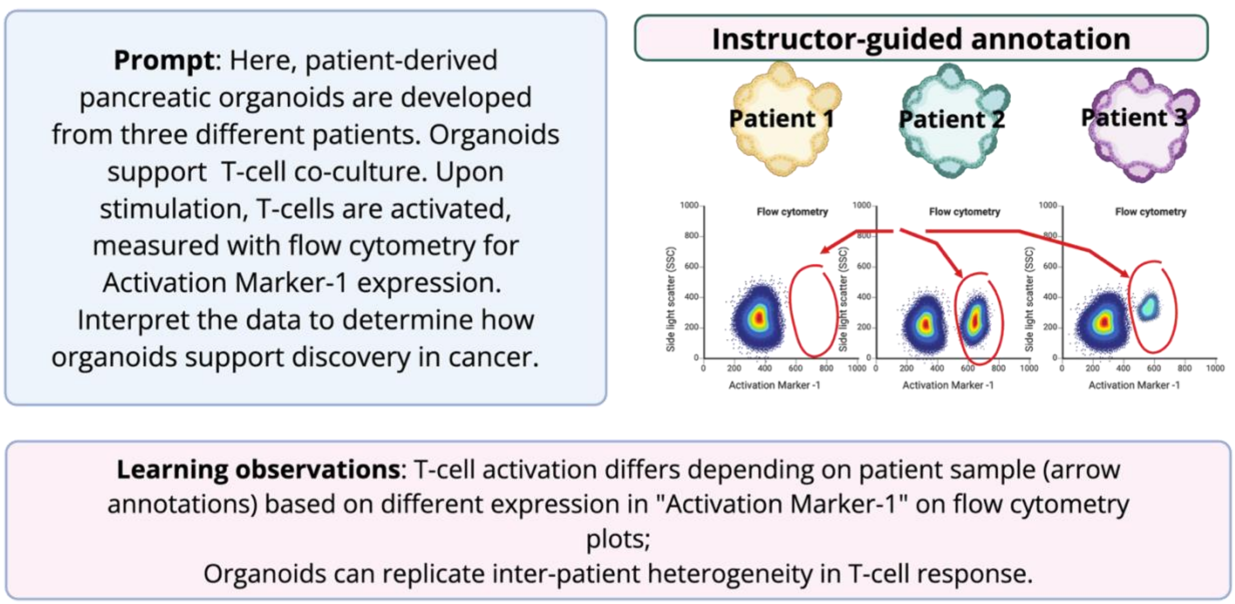

Figure 4*: An example prompt with accompanying illustration of scientific data. The prompt guided students to interpret the utility of organoid technologies in cancer discovery. The expected learning observations from this exercise were that organoid technologies may support patient-specific T-cell responses, specifically related in the illustration to varying levels of "activation marker" indicated via instructor annotations (red arrows).*

3.2 Inquiry-based learning created a joint problem-space, priming for interdisciplinary knowledge construction

With prompted data interpretation exercises, some students contributed by identifying methods used, while some others focused on the implications on the biological context. Students brought different perspectives to these discussions, based on their own interests, experience levels with undergraduate and graduate research, and knowledge about the broader cancer field. For example, while discussing the utility of mouse models vs. organoids in cancer immunology, students did not merely take away facts that organoid models were emerging technologies with high utility in cancer; rather they collaboratively identified trade-offs between mouse models and bioengineered models including the ability for bioengineered models to replicate inter-patient heterogeneity [19]. Some students contributed knowledge from their own experiences with cell culture in wet lab environments, while some others noted they had no experience with cell culture, leading to discussions about ease of access to these technologies. A particularly high quality class-wide discussion that ensued in the context of organoid use was to identify its potential in the development of new immunotherapies, a cascading notion that was unprompted. In order to arrive at this thought, students first identified the advantages in modeling human-specific immune responses over relying on translating immune responses from mouse models. Within groups, they deduced that therapeutic development could be performed and tested on human-specific and even personalized cancer models in vitro, leading to potentially targeted immunotherapies[20, 21]. These discussions demonstrated active analysis guided by unique student perspectives from research, industry internships, etc. demonstrating strong social construction of knowledge in the cancer bioengineering space.

3.3 Qualitative evaluations of collaborative annotations using MS Whiteboard as an additional scaffold for inquiry-based learning and social construction

Once MS Whiteboard was introduced as a collaborative annotation tool in Phase 3, it made student thinking visible to the instructor, almost providing an ability to visually trace their logic and inquiry. The shared visual Whiteboard space and student-led annotations were instantly visible to the entire classroom and the instructor across all groups. Analysis of student work on MS Whiteboard revealed diverse engagement levels with prompted course material. Many student groups actively annotated and interacted with the material, responding to prompts and with each other on the Whiteboard. Variability in annotation levels and quality are first demonstrated via illustrations in **Figure 5**, and quantified in **Figure 6**, suggesting that while the tool offered potential for enhanced collaboration, its adoption was influenced by individual learning styles and technology proficiency. Interestingly, annotation quality seemingly improved over the time course of Phase 3, reflected in reduced low-quality annotation percentages over time implying increased confidence and socially mediated competence. Similar constructivist activities like structured discussions and journal clubs in the biomedical engineering classroom have demonstrated that students develop competency in interpreting scientific data over time [22].

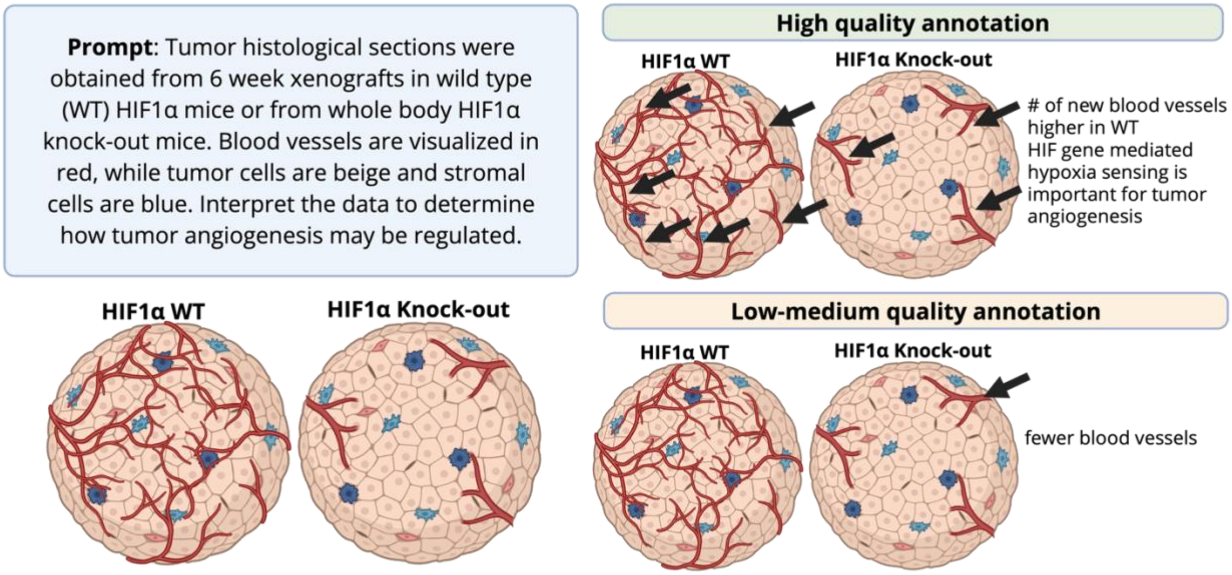

Figure 5: An example prompt with accompanying illustration of scientific data. The prompt guided students to interpret factors that may regulate tumor angiogenesis. High quality annotations made multiple markings (here illustrated via black arrows) on provided data and arrived at logical, well-articulated conclusions reflecting discussion depth. On the other hand, low-medium quality annotations had minimal markings and annotations and some to no explanations.

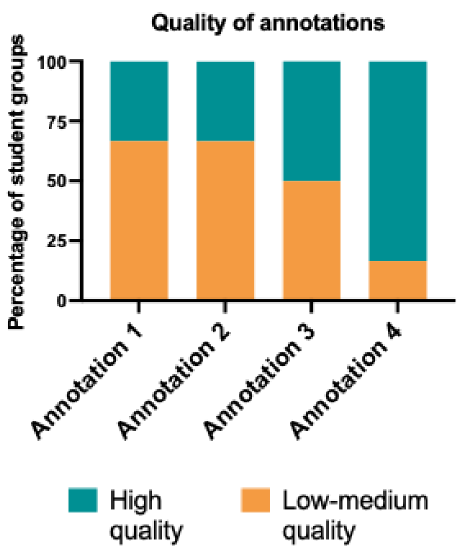

Figure 6: Across four annotation exercises during Implementation Phase 3, student work was analyzed by the instructor to classify them into a high-quality annotation or low-medium quality annotation. Over the course of the implementation phase, many more student groups switched to higher quality annotations compared to lower quality annotations, indicating growing confidence in interpreting scientific data over time likely due to socially mediated competency.

3.4 Shared visual spaces created by collaborative annotations increased discussion depth

Despite the high variability in annotation quality, instructor observations of student discussions noted that the visual space along with a prompt served as a focal point to facilitate good-excellent discussions. An example illustration of a high and low-medium quality annotations from prompted work is presented in **Figure 5**. Students were prompted to interpret scientific data to determine how tumor angiogenesis changed between wild type (WT) and HIF1-α knockout mice, and why. The expected learning outcome from this prompt was that students examine the levels of new blood vessels (illustrated here as red networks) between the two conditions and arrive at the conclusion that there are fewer new blood vessels in the knockout compared to wild type sample. Ideally, this conclusion allows students to reflect on the "*why*", requiring them to connect the visual dots to the concept that a growing tumor needs to sense the lack of oxygen before it can prompt new blood vessel growth[23].

Two disparate levels of student annotations are illustrated: low-medium quality annotations only identified basic trends in blood vessel count. High quality annotations identified trends in blood vessel count and connected the visual dots to the underlying biological mechanism of HIF1-α mediated hypoxia sensing. In both cases, however, discussions led to questioning why there were differences in wild type and HIF1-α knockout mice, and the role played by the hypoxia sensing gene in stimulating angiogenesis. Based on instructor observations, some groups with passive low-medium quality annotations required some additional prompting, or class-wide discussions to arrive at the central importance of hypoxia sensing as a driving mechanism for tumor angiogenesis.

Both within table groups and class-wide, however, discussion depth following collaborative annotations increased based on instructor observations due to the shared visual space, and ability to engage by digital inking with visuals instead of passive consumption. In the same illustrated example surrounding HIF1-α and hypoxia sensing, students brought unique perspectives on therapeutically targeting these pathways, identified ongoing or concluded clinical trials that used this strategy, and other biomaterials approaches for therapeutic delivery [24]. Depending on student's individual identities and experiences (internships in industry, exposure to wet lab research, shadowing doctors or clinical immersion, etc.), the classroom moved beyond accumulating facts (i.e. hypoxia sensing is important for tumor angiogenesis) to constructing knowledge around strategies for combating tumor angiogenesis knowing when it occurs.

3.5 Shared visual reference points via collaborative annotations positively impacted whole-classroom experiences beyond small-group learning

Having a shared visual space to interpret data and common reference points, students across groups often built upon each other's annotations and ideas. Particularly, the ability to see peers' annotations in real-time across the classroom was beneficial for understanding different perspectives. The ability to peek at other table annotations outside of your own meant that the whole classroom, rather than the small group, could be considered a unit of learning. This trend was especially identified during whole class discussions and review of annotations, where discussion quality was excellent, defined by exploration of concepts that were distal to the learning prompt and objective.

Another unique aspect of learning that emerged with the use of the Whiteboard was the peer-led scaffolding that popped up. An example of this is illustrated in **Figure 7**, where scientific data was presented with a prompt to identify how varying levels of externally applied strain changes cancer cell morphology and behavior. Typical high and low-medium quality annotation examples are depicted. All groups identified the trends in data that strain reduced cell circularity and increased its area, meaning that cancer cells sensed and responded to the mechanical microenvironment around them. Many groups discussed how these trends in cell shape resulted in invasive/metastatic behaviors. Interestingly, since all students had access to other groups' annotations, an independent annotation popped up (illustrated in **Figure 7**) demonstrating a visual illustration of the data trend of reduced circularity and increased area. Following this peer-led scaffolding, the class collectively synthesized new meaning for cell shapes/sizes and morphologies. Class-wide discussions of this concept were deep: students negotiated how cell morphology changes in response to microenvironmental mechanics are adaptive mechanisms for how tumors evade growth and space restrictions that are typically in place in the human body, and how they leverage external microenvironmental mechanical cues to override intrinsic programming for insidious gain[25].

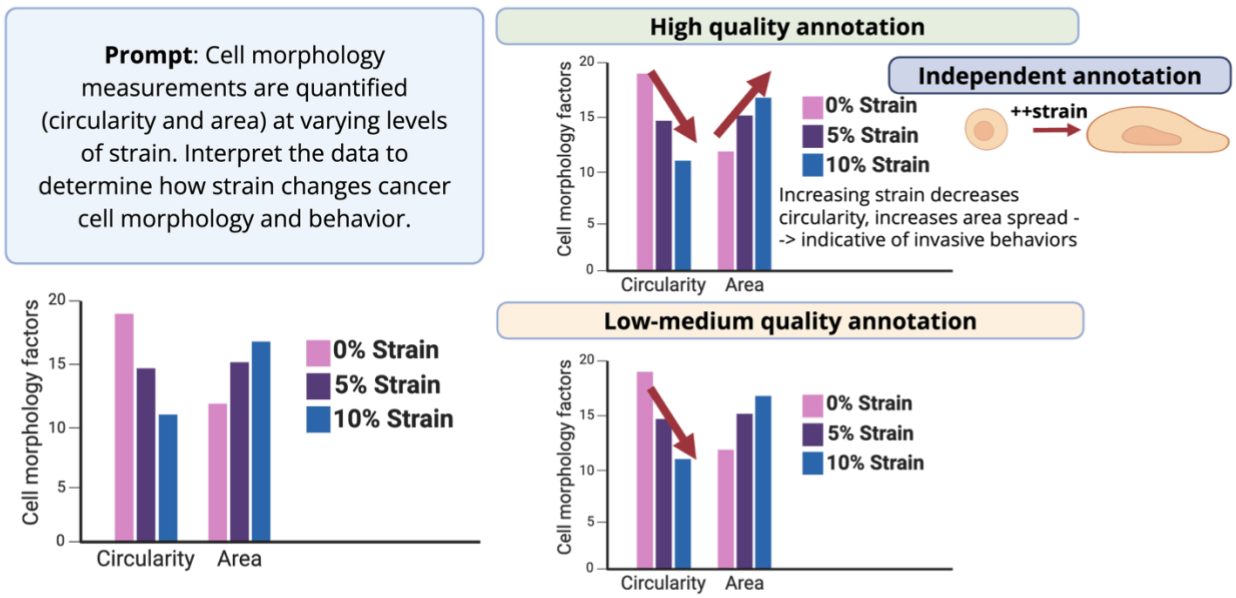

Figure 7: An example prompt with accompanying illustration of scientific data. The prompt guided students to interpret how externally applied strain levels may influence cancer cell morphology and behavior. High quality annotations identified both trends in bar graph data and a biological significance; low-medium quality annotations only identified trends. Independent annotations from outside the small group illustrated the bar graph trend of a cell sensing strain.

4 Lessons Learned and Future Opportunities

4.1 Bridging interdisciplinary gaps through shared perspectives in cancer bioengineering

Social constructivist learning in the Cancer Bioengineering classroom successfully bridged the interdisciplinary divide inherent in this classroom. Students brought different experiences and identities (undergraduate vs. graduate, experience in wet lab research vs. no experience in research, biology majors with no engineering background, industry experience vs. none, clinical experience vs. none) into BME learning, scaffolded by collaborative annotations and inquiry-based learning. These diverse experiences brought unique perspectives during scientific data interpretation and discourse, resulting in collective reorganization of thought in the cancer bioengineering context. Qualitative evidence and reflections suggest that the collaborative annotation space was a strong anchor for students to co-construct cancer biology and the power of bioengineering.

4.2 Mixed perceptions of MS Whiteboard utility in collaborative annotations

A key challenge encountered was the variability in student perceptions regarding MS Whiteboard's utility. Many students valued having their peers annotate or visually demonstrate their thoughts instead of just speaking them out. Students also conveyed that it was powerful for their own learning to be able to see peer notes across the classroom. Despite positive feedback, many others expressed frustration with the tool's interface, functionality and lack of integration into their personal note-taking workflows. The disparity highlighted the importance of not just diverse learning styles and preferences, but also technological skill levels within the classroom. Chief among student frustrations were technical performance issues on MS Whiteboard such as lag and difficulty manipulating objects on Whiteboard. These glitches, while seemingly minor, disrupted the flow of collaborative activities hindering their ability to fully immerse and engage with the material being presented. Future iterations will focus on better integration and access of co-constructed knowledge in the classroom to individual study and retention.

4.3 Instructor involvement in intentional group compositions

In this iteration, the instructor's role was primarily limited to scaffolding and facilitating discourse and creating opportunities for interaction. However, the ad-hoc formation of groups is a missed opportunity for more strategic peer-led scaffolding and social construction. Future offerings will utilize more intentional grouping, ensuring a good balance between graduate and undergraduate students, with/without wet lab and computational backgrounds, other professional experiences, etc.

4.4 Moving assessment and evaluation metrics beyond qualitative analysis

This study relied heavily on instructor reflections and descriptive observations of discussion depth and visible inquiry. While this qualitative data is essential for understanding the process of social construction in inquiry-based learning, future research will incorporate quantitative metrics to measure the impact via validated surveys. They will be designed specifically to evaluate how collaborative annotations and social construction improve learning outcomes in cancer bioengineering.

5. Conclusions

The interdisciplinary complexity of biomedical engineering has long necessitated a shift from instructor-centric lectures to social, constructivist environments that prioritize active engagement in different forms. This study demonstrated that introducing collaborative annotations through MS Whiteboard transitioned students to active investigators of scientific data in cancer bioengineering. By providing shared visual spaces, collaborative annotations facilitated deeper peer-peer discourse, allowing learners to bridge the gap between biological mechanisms and engineering frameworks effectively. Students built upon each other's insights, and collectively co-constructed a comprehensive understanding of cancer bioengineering. Ultimately, prioritizing visual and collaborative learning in the graduate setting highlights the beautiful complexity in the breadth of biomedical engineering.

6. Acknowledgements

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