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Using High Impact Practices to Broaden Undergraduate Participation in Computer Systems Research

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Abstract

The field of computer systems is intimidating to some students, even more so when researching this area. While previous researchers may have looked at pedagogy in other areas of CS, the specific challenges related to computer systems research have not been addressed much. Yet the problem is real and acute – single-digit participation from women, negligible numbers from other underrepresented groups. Thus, focusing on techniques that work well for those traditionally put-off by systems is imperative since systems are ubiquitous in every important aspect of CS today (artificial intelligence, cloud computing, security, etc.). This report describes a large diverse undergraduate research group in computer systems and the results of a study utilizing a conceptual framework, High Impact Practices, to understand how the design of the research group is perceived by students. The research group has expanded access to systems research to a broader group of students, many of whom have continued in the field. The assessment revealed that students are benefitting from the knowledge acquired and exchanged within the research group. This report is designed to share approaches we have implemented thus far, outcomes, and a reflection on areas for future improvement.

Keywords

Undergraduate research, diversity, inclusion, computer systems, practical skills, high impact practices.

1 Introduction

The field of computer systems has a woefully low representation of women and people of color. Our research team is designed to broaden participation in computer systems by providing a positive undergraduate research experience. Early CS research experience in an active research group with a focus on community building and support has been shown to yield positive outcomes on students' perception of and retention in Computer Science [1]. Our Computer Systems Genome project (CSG) provides community building and support

specifically within a systems research group. Key components of our team culture align with the 2018 report "Women in computer systems research: increasing community, awareness, and communication" [2].

The goal of this experience report is to share our strategies and study findings so that other research groups can consider similar management approaches to expand the number of students involved in computing research and broaden participation. Three of the authors are CS faculty advisors of the group and two of the authors are external engineering education researchers who did an initial study on the student experience. Our strategies create a supportive student research team that propagates the recruitment and retention of a diverse set of students in an area of computer science that traditionally lacks such representation of women, black students, and students with disabilities.

Table 1: Effective High Impact Practices Identifies by The Association of American Colleges and Universities (AAC&U) [3]

High Impact Practices	
1	High-performance expectations
2	Students investing a significant amount of time and effort
3	Faculty and peer interaction
4	Integration with diverse people and ideas,
5	Extensive faculty feedback
6	Reflective and interactive learning
7	Application of understanding to the real world
8	Public demonstration of competence

For this report, we used High Impact Practices as a framework to guide the assessment of the research group. We found that the design of the research group currently exemplifies 5 of the 8 characteristics of High Impact Practices: significant effort and time by the students, students understanding the relevance of learning, display of competence to a wide audience, facilitated faculty and peer interactions, and comprehensive feedback. The research group drives these research practices through research skills training, training in practical and computing skills, and relationship cultivation as shown in Figure 1. Several such students have chosen to pursue graduate studies in computer systems and others were placed in systems-related jobs in industry.

Figure 1: Key Strategies Used by the Computer Systems Genome Group

2 Related Work

Increasing diversity in computing and computing research are well-known challenges and the need to broaden participation in the more specific subfield of computer systems has also been acknowledged. While many universities have programs to increase students' practical software development experience and some projects have published about strategies to expand undergraduate research opportunities, our undergraduate research team specifically addresses the need to broaden participation in computer systems.

The report "Women in computer systems research: increasing community, awareness, and communication" discusses the findings provided by members of the NSF Computer Systems Research Principal Investigator meeting in 2018. The report outlines underlying reasons why women are particularly underrepresented in the computer systems research community and provides strategies to attract and retain women in computer systems research. Highlighted are the lack of community and support for underrepresented or underserved groups and the impression that this subfield of computer science involves "hardcore deep wizardry" with intimidating introductory courses. Suggestions are offered to improve communication about the creativity and impact of the field and to provide mentors with funding so that they can guide and support students. PIs should consciously establish a welcoming culture, be explicit and encouraging about office hours, and provide constant feedback, including positive feedback, to students [2].

In April 2018 the Computing Research Association (CRA) reported that according to the Center for Evaluating the Research Pipeline (CERP) data 72% of students surveyed had not participated in a formal research experience in college. The leading reasons students did not participate in research were that they prefer a more applied experience such as an internship and are not aware of research opportunities [4]. Low-income students do not participate in

undergraduate research because they seem to be less informed about research and its applicability to them, but they seem to also be more open-minded to these experiences than their higher-income peers. The report suggests that lower-income students may respond to individualized encouragement to participate [5].

The National Center for Women & Information Technology (NCWIT) provides research-driven best practices for encouraging women in computing. Recommendations to retain students by supporting them include providing positive faculty-student interaction, student-student interaction, role models, mentoring, and an inclusive physical environment. Such suggestions can be directly applied in both the classroom and in co-curricular experiences such as undergraduate research [6]. George et al. found that students who are engaged in computing groups are 30.7% more likely to maintain interest in a computing career and the association holds even when the proxy pre-test is controlled [7].

Students typically partake in some experiential learning within their computer science curriculum. Upper-level computer science courses are often project-based and thus students spend a semester obtaining experience on a development team with their peers. For example, at Grinnell College students can participate in an ongoing multi-semester web-based software project with a non-profit organization that includes a half-course that is an instructional introduction to the principle and practices of the project and a half-course that is working on the project itself [8].

The Early Research Scholars Program (ERSP) is designed to engage early-college CS students in active research groups using a structured course-supported group apprentice model with a dual advising structure to increase the number of CS students who participate in research. Its focus on community building and support encourages students who are from groups that are traditionally underrepresented in CS. Students in the program learn the fundamentals of CS research in a classroom setting and then apply this knowledge in an existing research group in the department. The program has had an impressive impact at UCSD and is expanding to other institutions [1].

Many institutions have various programs and models for broadening participation in undergraduate research across disciplines. The Vertically Integrated Projects (VIP) Consortium includes 45 institutions that implement this scalable model for high-impact multidisciplinary project-based learning that engages graduate students in leadership roles to make research teams scalable [9]. There are also several computer science-specific examples, such as at Duke University [10]. The Agile Research Studios model, developed at Northwestern University, uses an agile process, social structures, and studio tools so that faculty can potentially train 20+ research students [11].

Research experiences for undergraduate students are a form of High Impact Practices (HIPs) that has the potential to shape the experience of students while they are in college as well as

their professional experiences thereafter. The Association of American Colleges and Universities (AAC&U) has identified 8 different characteristics of effective HIPs: (1) high-performance expectations, (2) students investing a significant amount of time and effort, (3) faculty and peer interaction, (4) integration with diverse people and ideas, (5) extensive faculty feedback, (6) reflective and interactive learning, (7) application of understanding to the real world, and (8) public demonstration of competence [3].

3 Group Description

In our research group, we apply many of the principles represented in the above programs within a single computer systems research project. The project was born of an initial need to gather and study systems benchmarking data as the mission of the project is to conduct the first scientific effort to catalog the lineage of computer system performance over time to enable knowledge discovery and further understanding of the impact of computing innovations on transformative technologies, the knowledge-based economy, and societal change, csgenome.org [11]. Knowing that there would be large volumes of data to collect, investigate, analyze and connect to meaningful applications, we began to engage a large, diverse undergraduate team. The project spans the pipeline of gathering existing data, designing and implementing the repository, providing public access to the benchmarking and systems data, and demonstrating applications of the data with interactive visualizations and analysis notebooks as shared on the project website (www.csgenome.org).

Table 2: Group post-undergraduate outcomes

Overall Participants	45
Continued to Graduate Education in Computer Systems	6 (also one in data science)
First Job Placements for graduates	Amazon, Apple, Bloomberg, Booz Allen Hamilton, Facebook, JP Morgan, Microsoft, Mitre

In the Spring of 2018, we piloted the project with 6 students and, as shown in Table 2, by the Spring of 2022 had 45 students participating thus far with six continuing to pursue advanced degrees within computer systems, three of those having recently earned Masters of Science degrees. The research and development experience also bolsters students' preparedness for competitive internships and post-graduate employment at first-tier employers. The team is significantly more diverse than our CS department which is less than 20% female and less than 5% Black and Latino; and particularly more diverse than previous computer systems research project groups. Figure 2 details the student participation in the group over time and the consistent diversity of students not typically well-represented in computer science and especially not in the computer systems field.

One key component is faculty cooperation and collaboration. Three faculty members with a passion for inclusivity advise the group, each with different specialties: 1) systems research

and vision 2) systems research and practical skills expertise 3) CS education, inclusive practices, and project management. This and other intentional components are highlighted in Table 3 and discussed further below.

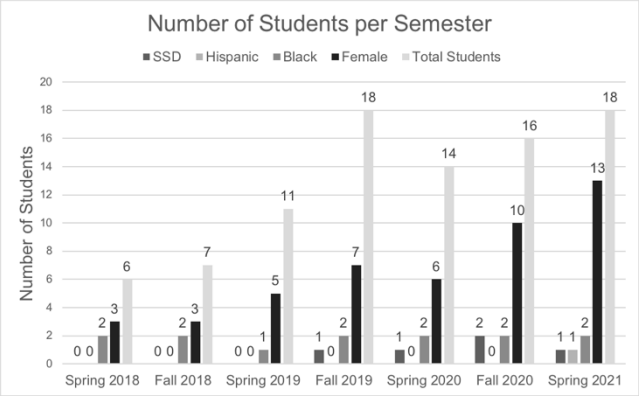

Figure 2: Total number of students on the computer systems research team per semester and underrepresented groups in computing. SSD stands for students with services for disabilities.

The components listed in Table 3 are extensions or variations of similarly successful or recommended approaches discussed in the Related Works Section. Similar to ERSP, our model has a designated faculty member who is more engaged at the introductory level to welcome the students, introduce them to the systems development experience, and expose them to basic research concepts such as literature review and giving their first presentations to the group. Other faculty members are more focused and specialized in systems research.

In line with the NSF CISE and CRA reports, our faculty attempts to be available, approachable, and provide regular feedback. We also recruit students early and provide an applied approach to research which CRA reports as desirable. By providing personal invitations to strong students from diverse backgrounds, we reach some students who had not previously considered undergraduate research as an option. Also, recognizing that empowering students can be motivating, we provide options for how and when they engage. They can participate as a volunteer, earn a wage, or earn credit and they can start immediately or defer. Additionally, students decide which area of the project interests them and they are encouraged to suggest new ideas in individual meetings [2,4].

We recruit students early and provide an environment with peers and student mentors. We aim to also reach students who may not even realize such opportunities exist so we invite students who are highly engaged in their coursework and/or are high performers. We also speak about our project at local events held by the Association for Women in Computing [13] and the Center for Enhancing Engineering Diversity [14].

Students are on-ramped with a series of tutorials and set-up instructions, they learn to reach out to peers and faculty members in addition to wiki instructions and videos. Students enter with various levels of course and personal computing experience. Students learn and practice these skills alongside supercomputing, benchmarking, architecture, and performance.

Table 3: This table highlights the components of the research group intended to create a supportive community and broaden participation in the computer systems subfield of computer science.

Component	Details	Related Work
Faculty Roles	Research expertise, practical skills expertise, project management skills, experience with inclusive practices, instructional strategies, general mentoring and advising	ERSP, NSF CISE
Student Recruitment	Recruitment of a diverse set of students enrolled in CS2-level courses with options to volunteer, earn, undergraduate research credit, or become a wage employee	CRA
Practical Skills Acquisition	Acclimate students to version control, Linux, development environments, python, and project subgroup-specific technologies with training tutorials, videos, documentation	CRA, NSF CISE, Grinnell
Research Skills Training	Introduce and practice literature surveys, publication reviews, research methods, and LaTeX	ERSP, ARS
Cultivate Relationships	Assign tasks to pairs of students, providing in-group mentors for students, and communication with recent graduates with regular feedback and opportunities for decision making	ARS, VIP, NSF CISE, HIP
Contact Time	All-hands team meetings and working sessions with various subgroups according to technical area and also for new students and advanced research students	NSF CISE, HIP
Multiple Modes of Communication	Communication using Discord, git issues, emails, and weekly updates via google docs with faculty feedback	ARS
Interdisciplinary	Multiple subfields of CS and the opportunity for meaningful applications	VIP, HIP
External Exposure	Presentations, conferences, website, publications, educational outreach, continue to graduate education	ERSP, VIP, ARS, Grinnell

As shown in Figure 3, the project introduction points students to a primer that walks students through options for setting up their development environment either locally on Linux, a Virtual Machine, Windows Subsystem for Linux(WSL), or on a development server. Then the introduction provides guidance on setting up Git, a Python virtual environment, and an

Integrated Development Environment(IDE), along with team policies for code style, issue creation, branch creation, and merge requests. In the introduction and on the main tutorial page, students are directed to internal and external tutorials that include videos, text, and sample code to run and edit. For example, students are pointed to in-browser tutorials for learning and practicing git and D3.js and are also given instructions about SQLAlchemy with a series of internal tutorial python notebooks to run and edit. Students work through the tutorials that are most relevant to their interests, typically either frontend development skills such as react, next.js, Material UI, and D3.js, or backend development skills such as python and SQLAlchemy. Some students start off using python to display and analyze data which provides a gentle introduction and can also provide additional testing for updated API endpoints. The Wiki is filled with approximately 60 student-generated Wiki pages in addition to what is displayed in the right panel of Figure 3.

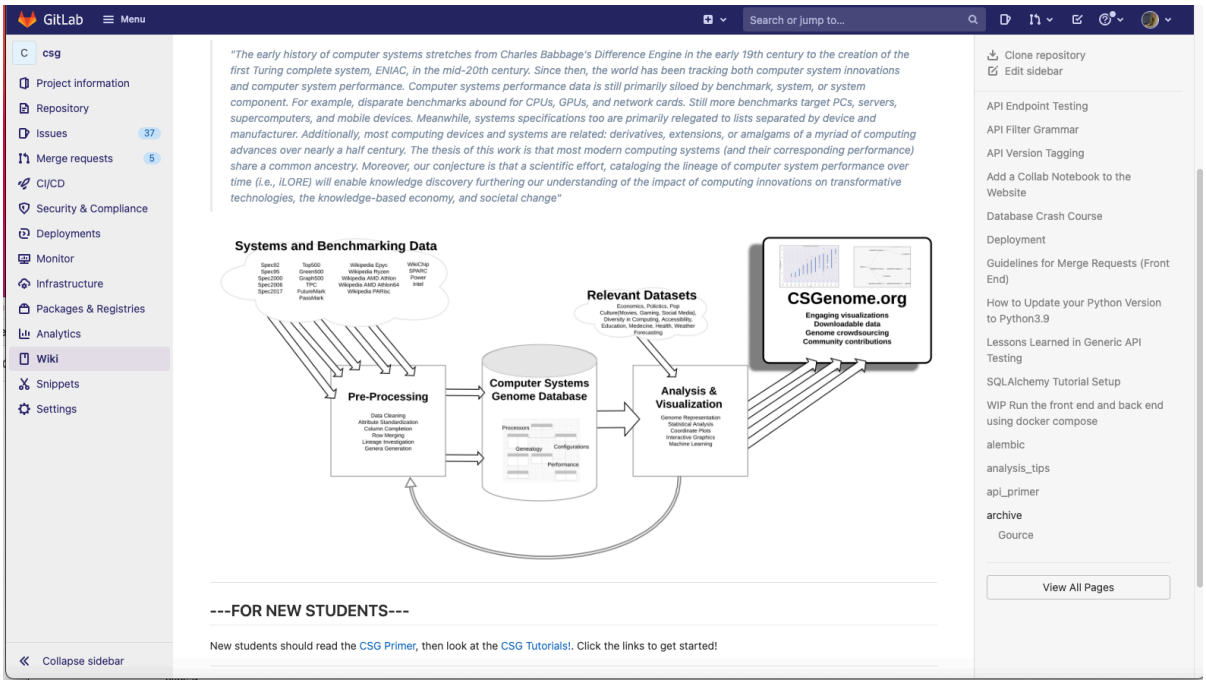

Figure 3: Introductory Wiki page for onboarding

The team is explicitly supportive so that even when the content may seem complicated or overwhelming, students are encouraged to persevere and are provided with resources, feedback, and peer role models. We are very focused on the work but make a point to start large meetings with ice breakers, such as “What is one of your interests not related to computer science?” or “What movie or show did you watch over break?” in addition to having students share which classes they are taking as a bridge to help students connect and feel more comfortable. Students have regular casual interaction with each other and time and space (whether physical or virtual) are provided so that the team has open-ended working time together to allow for unstructured friendly conversations and incidental learning. We have initiated a tradition of having a panel discussion for team alumni to share their undergraduate and post-graduate experiences with current students.

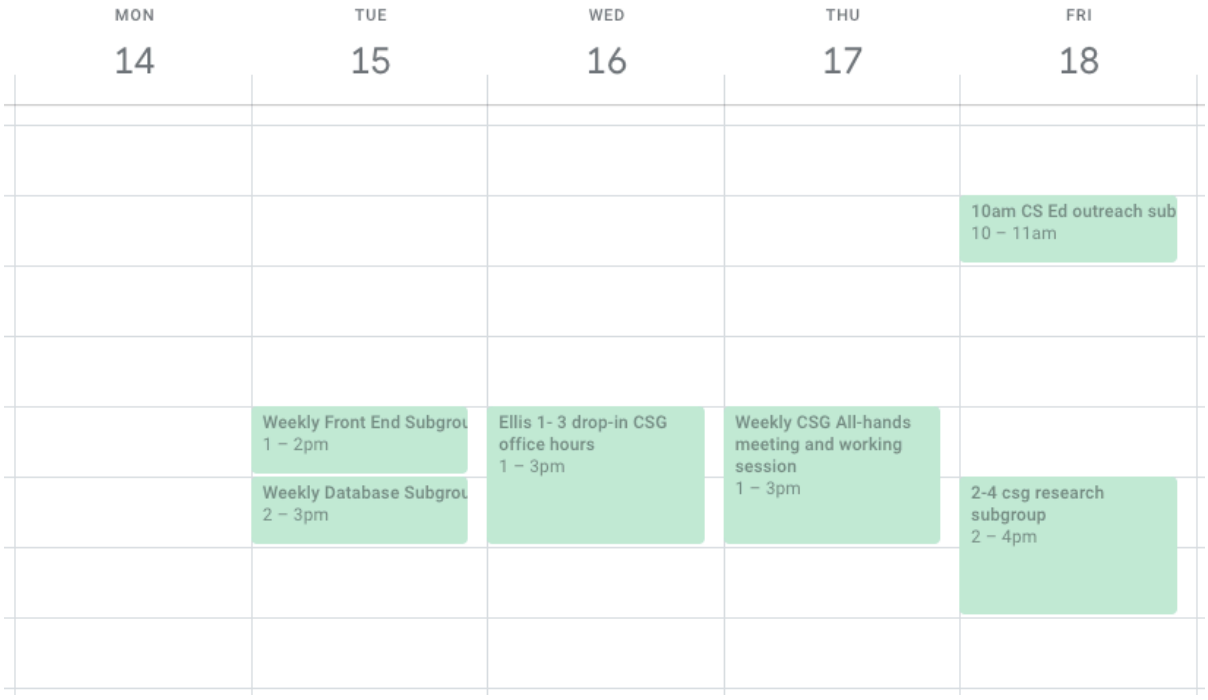

Figure 4: Weekly group schedule during the online Spring 2021 semester

In addition to larger group meetings with more formal presentations and code or design reviews, we have smaller meetings and subgroups so that students are more comfortable participating and interacting. The subgroups and schedules vary each semester, but an example from Spring 2021 can be seen in Figure 4, in Fall 2021 there were more students and daily 2-hour in-person working sessions where students gathered in subgroups. Advanced students also attend the weekly lab meeting of one of the faculty members and participate in paper reviews. Students are expected to collaborate and help each other, e.g., the more advanced students create tutorials with faculty consultation. In our recent all-online work environment, we have pre-recorded video tutorials by lead students for the team and we record informative zoom sessions. Many of the conversations are not professor-driven, rather professors listen and step in to encourage or guide as needed. On a larger scale, our project aims to influence the perception of and communication about computer systems research to a broad audience by making our repository, analysis, and educational materials available through the project website (www.csgenome.org).

Students have timely access to peers and faculty across a broad range of communication modes such as Discord chats and channels, emails, git issues, and weekly individual updates in a personal google doc to which a faculty member responds weekly. Students spend time brainstorming, planning, designing, coding, problem-solving, and communicating across a

variety of sub-projects such as web scraping, data cleaning, database design, API development, testing, front-end development, systems component research, systems performance analysis, and visualization creation [15,16]. Importantly, the open-ended nature of the research provides flexibility to support students in following their interests.

Several students on the project have continued on to graduate studies with the professors either on the same project or a different systems-related project. Several students have had the opportunity to present at university academic conferences and the Capital Area Women in Computing conference. Students have also attended the Supercomputing conference with the research team. As the project matures students' work will be submitted in publications.

4 Conceptual Framework and Research Design

To help understand the student experience in the research group, our engineering education researchers surveyed students. After IRB approval, an anonymous survey was sent to all of the current students and alumni to better understand their experience within the group. In total, 18 people participated, which included 4 previous students and 12 current students, 5 of those students were interviewed. The questions for the survey and the interview were formulated around the elements of quality by Kuh and O'Donnell. The qualitative analysis methods used were thematic analysis and codebook development. These were used to identify patterns of themes across the student interviews [3].

The context of this study is different from other HIPs (i.e. first-year seminars), in that students are not required to participate. We are aiming to understand the perceived quality of the experience to promote student engagement. To capture the perception of students in regards to their experience within the research group, we used the 8 key elements of quality as defined by Kuh et. al.: high-performance expectations, significant effort and time demonstrated by the student, facilitated faculty and peer interactions, comprehensive feedback, experience with diversity in regards to people and circumstances, structured opportunities to integrate learning, students understand the relevance of learning, and the display of competence to a wide audience. This framework was used to analyze the data from the survey and aid in the analysis of the interviews to contextualize the student experience with the research group [3].

5 Results (Student Experiences)

The Computer Systems Genome research group aims to provide research experiences to students with little or no background in research. By having a low technical barrier to entry, students from non-traditional, as well as diverse backgrounds, are encouraged to participate.

Many participants expressed how this was their first time having this type of research experience, they found that they were not only able to gain the knowledge on how to do research but technical concepts and skills relevant to the workplace as well. As shown in Figure 5, the overall perception of the group was overwhelmingly positive in regards to how the group prepares them for the workforce, how learning is shared within the group, and how they felt like they belonged within the group.

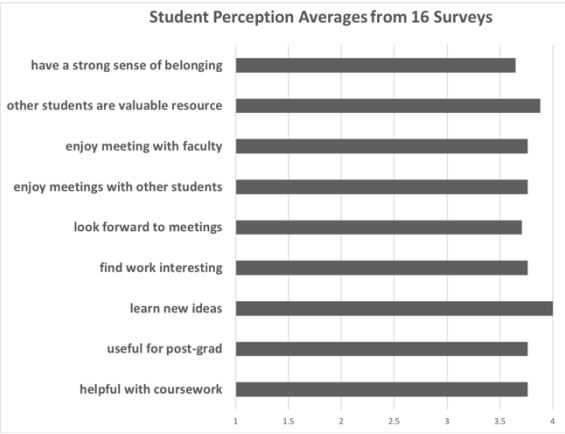

Figure 5: Survey results from 16 current and previous students' responses were on a scale from 1-4: Strongly Disagree, Disagree, Agree, Strongly Agree

5.1 Knowledge Acquisition

As shown in Figure 6, the knowledge acquisition theme contained 3 different elements of HIPs: significant effort and time by the students, students understanding the relevance of learning, and display of competence to a wide audience. These 3 qualities of HIPs are exhibited throughout this section, which details how students are able to gain knowledge (i.e. technical and soft skills) applicable beyond the projects assigned to the students within the group.

In balancing the added responsibility of being part of the team, students are able to gain skills such as problem-solving, communication, time management, and project management. For example, when a participant was reflecting on their experience, they said, *"the research experience and the experience working with others and managing time that came from CSG, a lot of those skills helped later in my other work [such as] my internships."*

The tools and resources (i.e., Python, git, databases, website development) are used within the workforce and are valuable skills for coursework and obtaining internships. Students expressed how they learned a new language and produced data visualizations, which are tasks that they had not previously done or were not previously exposed to. For example, a

participant said, *"I learned how to do Python, that's one thing...a lot of data science and data visualizations that were completely new to me so I learned everything about data visualization from CSG."* The skills that the students learned were not solely specific to the research group but also applicable within the workplace. For example, another student said, *"I would say we used a lot of Python in my internship...so the projects CSG definitely helped me out with a lot of Python there."* Furthermore, a student attributed their ability to obtain an internship to the group because recruiters were interested in the group as well as how integral the student was to the success of the project. The student said, *"Things where you chose to do it so you know it's your free time you chose to do it, but it's also something that's kind of verifiable [than] a personal project...with CSG you can say, 'here's the website, and this is here because of me."*" By understanding the relevance of their learning and producing a tangible product to show others, students can demonstrate their impact within the field of computer systems as an undergraduate student.

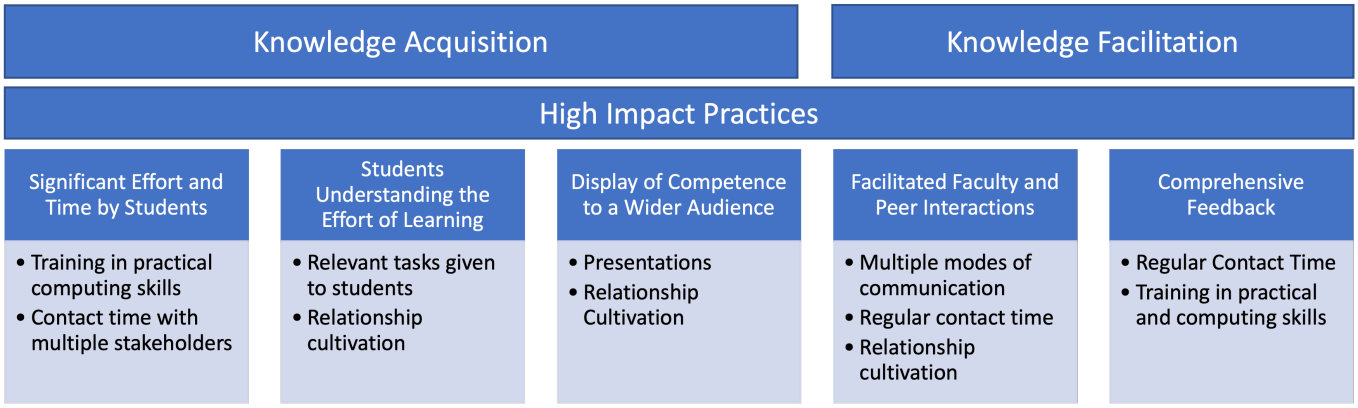

Figure 6: High impact practices and their corresponding themes identified within the assessment

The students expressed how they had preconceived notions of doing research before their participation in the research group, thinking that they thought research was only *"reading articles and writing papers."* Their actual experience working on applied research projects, however, aligned with their interests, whether that be on the software or the hardware side of the project. The components of the project help students gain skills in problem-solving, communication, time management, presentation, and project management. A participant described the experiences within the research group as a *"mini internship*" because of the practicality of the projects in relation to academia as well as industry. This participant further said, *"CSG helped me ... my classes like we did JavaScript and I was like oh I've done a little bit of this...just working with the team has been good to learn how to communicate with all my team members make sure I'm doing that but yeah it's been good to learn those kind of soft skills as well as the coding skills*."

The technical and soft skills that the students learn extend beyond the boundaries of the group itself. The projects help students understand the practicality of the knowledge they are gaining, which are desired qualities of HIPs. The knowledge that they are gaining is strengthened by the ways in which knowledge is shared between faculty and students.

5.2 Knowledge Facilitation

As shown in Figure 6, the theme knowledge facilitation contained 2 different elements of HIPs: facilitated faculty and peer interactions and comprehensive feedback. These 2 elements of HIPs are discussed in this section by describing how knowledge is transferred between students and faculty within the group.

It is important that students are willing to communicate among the stakeholders in the group. For CSG, the stakeholders are students and faculty. A participant shared, *"[In class] it's more of 'I don't want to talk to you ever again' kind of thing. But CSG felt more connected, it's not like we're just doing homework, it's more like we're contributing to a greater goal, which makes me feel good, which makes me feel more connected with people. So, from that, I learned more about how the team communicates because miscommunication happened right so [I think about] how do we avoid this and find how to set reasonable expectations [in the future]."* The environment cultivates collaboration among its members. Students have to communicate with faculty and their peers within the group to complete the projects. Faculty and students provide support on the project as well as learning material. For example, a student said, *"...coming into CSG, you don't need to know anything special because we have the resources to help you learn, the professors are especially great about serving as a resource for that, and being really open to [project exploration]."*

Having faculty and students be open to learning and providing resources for students helps promote an environment of knowledge sharing, which is advantageous within and outside of the research group. Another participant said, *"...since I'm working with other students and professors like I have gained that kind of resources well like I'm like I'm like oh I can like ask this person about my actual classes and stuff like we can work on like other classes and stuff like that"* The knowledge that is acquired by the students supplements what they are learning within the classroom. A participant said, *"...it's just been fun to have that creativity and also still be able to learn more and it still helped me … my classes … in my one of my classes like we did JavaScript and I was like oh like I've done a little bit of this so it's been helpful and, in my classes, as well."*

Students are encouraged to seek help from their peers and from the faculty advisors within the group. Faculty are able to provide feedback on their projects and situate the work that they are doing within the larger context. For example, a participant said, *"[The PI] will ask great questions like, what does this mean in context. How can you relate this to some of the*

other analysis that has been done in the past? He's really good at the higher level like analysis and relating the work that we do to a broader context." The participant further explained that because of the understanding of their work within the context of the project and the larger context, it made them feel like an integral part of the team and promoted their engagement.

In addition to meeting with faculty, many of the current and past students of the group expressed in the survey that they looked forward to meeting with other students in the group and considered other students as resources. While in the interviews, many students conveyed how they leveraged the knowledge of other students to do work within the research group, participants also discussed how they utilized other students for advice outside of the group. For example, a student said, *" So for me it's been fun to like, learn about what other people are doing and, like, for example like when I'm trying to decide with my capstone I can talk to, like, there's like a senior in our group and like I'm going to talk to her about what she's done with her Capstone because it kind of helps me like choose what I want to do with my classes as well and kind of like having a better understanding of what our actual classes have to offer and whether they're good fit for me or not."* A student's experience within their undergraduate education is composed of many facets and through the relationships built in the research group, they are able to leverage these relationships in multiple ways.

The ways in which students are collaborating with each other and faculty in the group are indicators of facilitated faculty and peer interactions and comprehensive feedback, which are qualities of HIPs. By students and faculty communicating in relation to their work within the group as well as outside of the group, they are able to develop deeper relationships with each other as shown in their interview quotes. The way the group is designed to supplement what the students are learning in the classroom and promote communication among its members helps promote an environment of collaboration.

6 Future Work

While our assessment of the group did not reveal factors that directly pertain to a member's sense of belonging within the group, the design of the research group needs to further consider this in the future. We intend to further study the impact of this undergraduate research experience on students' overall sense of belonging in Computer Science [17] and continue to adjust our strategies in hopes of broadening participation in Computer Science and more specifically within the field of Computer Systems.

7 Conclusion

Overall the strategies used to build and support this team help accomplish high-impact practices as detailed in Table 2. As indicated in Table 3, variations of many of these

strategies are implemented across various computer science research teams and experiential learning opportunities. These strategies are aligned with the characteristics of quality for HIPs as they encourage the participation and engagement of students in the computer systems community as a whole. The participants expressed how they were able to gain internships, jobs, and be less "afraid" to explore different concepts within the computer systems field because of their participation in CSG. As contextualized by the interviews, the leadership of this research group is what helped guide the practices of this group. When designing the Computer Systems Genome group, the advisors of the research group were intentional in regards to how knowledge was acquired (i.e. student's assigned projects) as well as how their acquisition of knowledge was facilitated (i.e. training material, peer teams, peer mentors, faculty, and peer discussions). The intentionality of the experiences of the students helped create a culture of learning. From the assessment of our practices within the group, we were able to understand how students perceive the design of the Computer Systems Genome research group in relation to their experience within computer systems.

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References

[1] M. Barrow, S. Thomas, and C. Alvarado, "ERSP: A structured CS research program for early-college students," in *Proceedings of the 2016 ACM Conference on Innovation and Technology in Computer Science Education*, Arequipa Peru.

[2] L. Golubchik and J. Weston, "Women in computer systems research: increasing community, awareness, and communication.," National Science Foundation, USA, Technical Report, 2018.

[3] G. Kuh, K. O'Donnell, and C. G. Schneider, "HIPs at ten," University of Wisconsin Oshkosh, 2017.

[4] "Understanding why many undergraduate students don't participate in research," *CRN*, May 14, 2018. https://cra.org/crn/2018/04/understanding-why-most-undergraduate-students-dont-participate-in-research// (accessed Aug. 12, 2021).

[5] "Compared to peers, students from low-income backgrounds report less awareness of – but greater interest in – formal research experiences," *CRN*, Jun. 02, 2021. https://cra.org/crn/2021/06/student-interest-in-formal-research-experiences/ (accessed Aug. 12, 2021).

[6] "Retain with Student Support. Create a sense of belonging and identity as a member of the field" https://ncwit.org/retain-with-student-support-create-a-sense-of-belonging-and-identity-as-a-member-of-the-field/(accessed Jan. 30, 2022)

[7] K. George, L. Sax, A. Woffard, and S. Sundar, "The tech trajectory: examining the role of college environments in shaping students' interest in computing careers," in *Research in Higher Education*, Jan 2022, https://doi.org/10.1007/s11162-021-09671-7.

[8] J. Davis and S. A. Rebelsky, "Developing soft and technical skills through multi-semester, remotely mentored, community-service projects," in *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, Minneapolis MN USA, Feb. 2019, pp. 29–35. doi: 10.1145/3287324.3287508.

[9] VIP Consortium | Vertically integrated projects." http://www.vip-consortium.org/ (accessed Aug. 12, 2021).

[10] "CS+: CompSci projects beyond the classroom | Duke Computer Science." https://www.cs.duke.edu/undergrad/summer_research (accessed Aug. 12, 2021).

[11] H. Zhang, M. W. Easterday, E. M. Gerber, D. Rees Lewis, and L. Maliakal, "Agile research studios: Orchestrating communities of practice to advance research training," in *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, Portland Oregon USA, Feb. 2017, pp. 220–232. doi: 10.1145/2998181.2998199.

[12] "Computer Systems Genome." https://csgenome.org/ (accessed Aug. 12, 2021)

[13] "Association for Women in Computing (AWC) - Home." https://www.awc-hq.org/home.html (accessed Aug. 12, 2021).

[14] "Center for the Enhancement of Engineering Diversity (CEED)." https://eng.vt.edu/content/eng_vt_edu/en/ceed.html (accessed Aug. 12, 2021).

[15] N. Hardy, “iLORE: A Data Schema for Aggregating Disparate Sources of Computer System and Benchmark Information,” Master’s thesis, Dept. Computer Science, Virginia Tech, Blacksburg, VA, 2021 http://hdl.handle.net/10919/103707

[16] S. Furman, “iLORE: Discovering a Lineage of Microprocessors,” Master’s thesis, Dept. Computer Science, Virginia Tech, Blacksburg, VA, 2021 http://hdl.handle.net/10919/104071

[17] S.K. Moudgalya, C. Mayfield, A. Yadav, H. H. Hu, and C. Kussmaul. 2021. Measuring Students’ Sense of Belonging in Introductory CS Courses. Proceedings of the 52nd ACM Technical Symposium on Computer Science Education. Association for Computing Machinery, New York, NY, USA, 445-451. DOI:https/doi.org/10.1145/3408877.3432425