How to Guide Undergraduate Research

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Goals of Undergraduate Research

Knowledge production

Student development

Develop specific skills

Learn to apply specific techniques

Learn to think critically

Develop problem solving skills

Develop patience and perseverance in pursuit of knowledge

Target Undergraduate for this Discussion

High school grad with no prior CS experience

3-4 CS courses & no summer internships

3rd/4th year CS major with summer internship

Finalist at Intel Int'l Science & Eng. Fair

Less experience

More experience

Caution: Don’t assume students are like you

Personalities, Aptitudes, and Skills Vary

Motivation and interest in research and computer science	• They likely don't know what research is
Learning independence and perseverance	• They likely don't have a systematic approach to learning or finding information
Technical skills and knowledge	• They likely have not mastered basic technical skills • They likely will remember general, not specific, knowledge

Practical Advice for Advising Students

- Finding students to work with
- Characteristics of good research projects
- Setting expectations and creating a plan
- Developing students' technical skills
- Developing students' research skills
- Teaching students how to communicate their contributions
- Being a good mentor
- Resources

Identifying Students to Recruit

- Students who have done reasonably well in your or trusted colleague's classes
- Students who have shown initiative at solving problems on their own before asking for help
- Students who have shown genuine interest in CS topics
- Students whose personalities and work habits can work with yours
- Students who can work well in a pair or group setting

Recruiting Students to Work with You

Explicitly invite students to talk to you

Consider group arrangements

Pair of students working together on project

Group of students working on closely related projects

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Matching Students with a Project

Less experienced students or shorter projects	• Create set of related problems and let students choose or suggest variant
More experienced students with longer projects	• Provide student with several papers, ask them to look at related work, then have them propose ideas

How to Create a Good Research Project

Make sure it's a topic you are invested in and excited about

Make sure it will fit into the allotted time

Choose something that will likely be successful

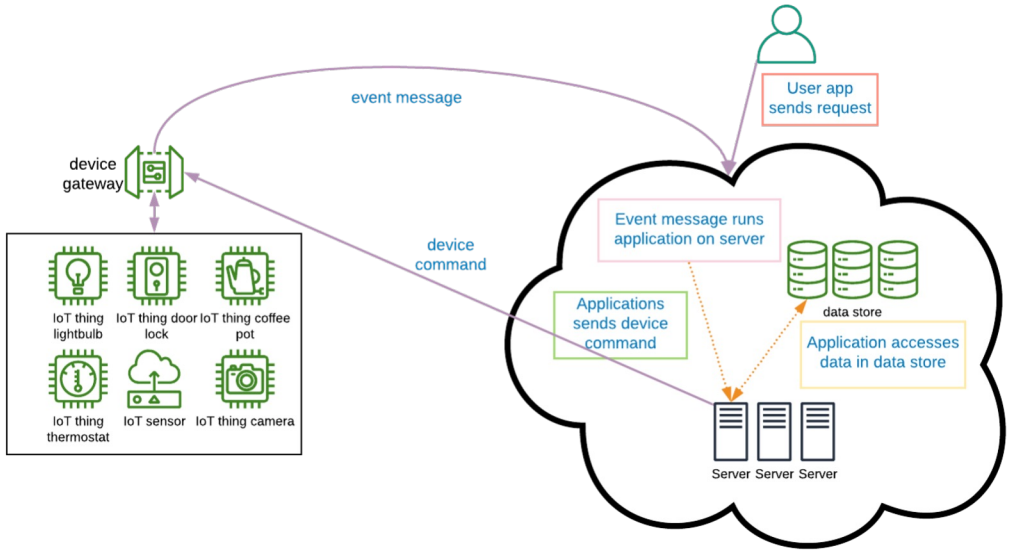
Ensure it takes a student through the entire research process

Additional Good Project Characteristics to Think About in Advance

- Ensure it consists of concrete, focused tasks for student to do
- Try to have it generate data that the student can present
- Ensure it includes built-in difficulties that will challenge the student
- Make sure student possesses needed skills or could learn skills quickly with guidance

Example Good Summer Project: IoT Apps

- AWS IoT APIs allow unrestricted concurrent updates to data



- Question: Do developers use API correctly to avoid conflicting data updates?

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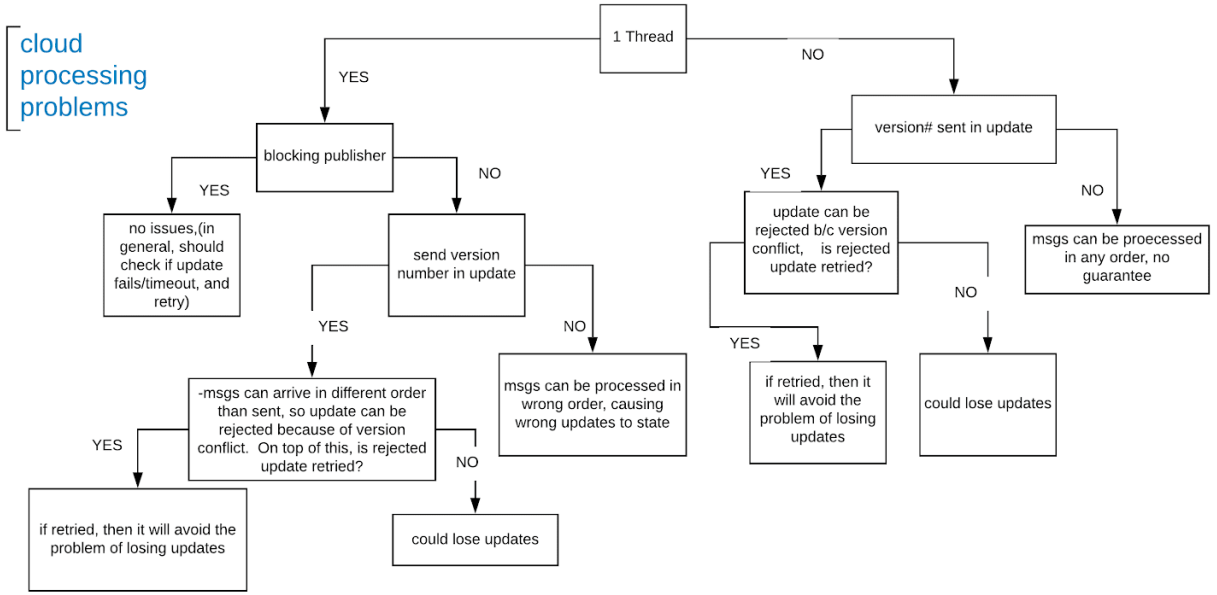

- Approach:
  - Understand API features and underlying platform
  - Develop flowchart to determine when API will allow erroneous data updates
  - Construct a static analysis tool to analyze source applications using flowchart

Example Good Summer Project : IoT Apps

- Challenges:
  - No prior exposure to concurrency, static analysis, JavaScript, IoT cloud platforms
  - No prior experience using incompletely specified API
- Outcomes:
  - Constructed prototype for analyzing AWS IoT JavaScript apps for part of flowchart
  - Analyzed set of applications found on Github
  - Poster at SIGCSE Student Research Competition

Example **Poor** Semester Project: IoT Apps

- **Google** IoT APIs allow unrestricted concurrent updates to data
- Question: Do developers use API correctly to avoid conflicting data updates?
- Approach:
  - Understand API features and underlying platform
  - Develop flowchart to determine when API will allow erroneous data updates
  - Construct a static analysis tool to analyze source applications using flowchart
- Challenges:
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  - No prior experience using incompletely specified API
- Outcomes:
  - **Basic understanding of Google IoT API**

What went wrong?

Time

- Student had limited time to work during semester
- I had limited time to learn material to help student

Meetings

- We only met weekly so long delays when student got stuck

Topic-specific issues

- Limited knowledge about composing JavaScript applications including compilation infrastructure
- Google IoT environment more complicated and confusing than AWS

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Setting Clear Expectations*

- Overall goal of the collaboration
- Expected work hours and number of hours
- Frequency of one-on-one meetings
  - Mentee and mentor preparation for meeting
  - Pre- and post- meeting communication
- Frequency of and involvement in group meetings
- Mechanism for and frequency of communication
- Ways to get daily help

*Mentor compacts/contracts

When to Advise Research

Summer internship

- Extreme focus
- Frequent interactions

Academic year

- Slower progress, weekly interactions
- Induces more stress because balancing with course work

Combination

- Pre-summer ramp up
- Post-summer write-up

Creating a Summer Internship Plan

Week 1:
- Read and discuss small set of papers explaining problem
- Discuss approach to be taken

Weeks 2-3:
- Learn specifics of tools to be used
- Experience or observe the problem being explored

Weeks 4-7:
- Design and construct artifacts needed for experiments

Weeks 8-9:
- Collect and analyze data

Week 10:
- Determine future work
- Write-up research and documentation

Example Research Progression : IoT apps

Week 1	• Read papers about IoT challenges with respect to concurrency • Read papers that applied static analysis approach in related contexts
Weeks 2-4	• Experimented with AWS IoT Java and JavaScript APIs • Collected sample set of AWS IoT apps from Github
Weeks 5-7	• Created flowcharts indicating when use of API would be erroneous
Weeks 8	• Learned about static analysis and Babel AST tools
Weeks 9-10	• Implemented static analysis tool to collect relevant API usage
Weeks 10+	• Created SIGCSE poster application and created poster

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Students May Have Limited Knowledge About

How to find resources online

How to install software

How to interpret tool warnings and error messages

How to search for solutions to specific tool problems

How to read code and documentation

How to design, test, and debug code systematically

How to document their code

How to use a version control system

How to create figures

Apprentices Need to Be Shown How

- Learn material with them to be able to answer questions and guide
- **Always** give them a chance to figure something out on their own
  - But don't give them a long time
- Have them show you what they have done and ask for rationale
  - Provide constructive feedback for improvement
  - Ask how they have tested their approach
  - Ask if they considered other approaches, suggest alternatives
  - Help them consider which approach to take and work with them through the thought process
- Demonstrate how to do tasks, describing your process generally
  - Don't be afraid to pair-program or debug with them

Example Hands-on Advising: SW Installation

Choose an IDE to use for Groovy language

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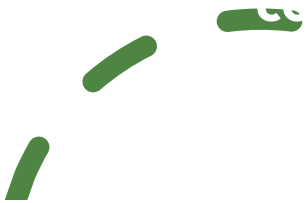
  - Questions about how to install JDK because of Oracle policy changes
  - **Pointed out missed info in documentation and explained steps to be taken**

Example Hands-on Advising: Debugging

Import static analysis library and create program to find methods



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- Created tool that discovered some methods
- Method names with specific parameter lists unrecognized
  - Ignored error message being printed out for one of those missing methods
  - **Pointed out error message was useful and demonstrated how to use IDE to understand error**
  - **Walked through process of figuring out functionality of API**
  - **Encouraged getting sample code to run and directly comparing**

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Explaining the Research Process

- Use example research projects for reference
  - Describe a past student project
  - Describe how their class project could be expanded to research project
  - Provide them with a research paper to read
- Discuss the research steps taken in those projects and generalize
- Discuss the research steps in the context of their project
  - Both initially and as they work through their research project

Help Students Learn Research Skills

How to read a research paper

How to find related work

How to keep notes on their progress and useful resources

How to design a set of tests to check for correctness of their results

How to design a set of experiments

Collaborate on experimental design

- Link experimental design back to research hypothesis
  - Help them walk through what results to collect to test hypothesis
  - Help them understand the need for baseline results
  - Help them understand what variables can be varied
  - Help them understand how to systematically test suite of variable combinations
  - Help them understand how to set up the experimental environment
- Discuss the prioritization of experiments with respect to evaluating the hypothesis

Example Experimental Design Process

Prior work: Detected and prevented data inconsistencies in distributed database using weak consistency guarantees

Our expansion: Store Mozilla WebThings IoT device data in database

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  - Experimentally evaluated latency of WebThings request generation
  - Recreated experiments performed in prior work using new WebThings latencies

Example Experimental Design Process

Prior work: Detected and prevented data inconsistencies in distributed database using weak consistency guarantees

Our expansion: Store Mozilla WebThings IoT device data in database

- Recreated prior work's experiments using our modified system
  - Experimentally evaluated latency of WebThings request generation
  - Recreated experiments performed in prior work using new WebThings latencies
- Examined factors that weren't varied in prior work
  - E.g. Number of clients, policies specifying which servers perform work
  - Design experiments that vary those factors using new WebThings latencies

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- Finding students to work with
- Characteristics of good research projects
- Setting expectations and creating a plan
- Developing their technical skills
- Developing their research skills
- Teaching them how to communicate and document their work
- Serving as a good mentor
- Resources

Establishing Documentation Expectations

Students ***will*** move on and you'll want to continue to use their work

Set expectations early and reinforce by reviewing student work

What Documentation Should You Require?

Create shared research notes online

- Related work
- References to online documentation
- Step-by-step processes for
  - setting up the system and
  - using the system, including ways to modify parameters or behavior
- Daily progress including results

Provide comments in software

Establish shared code repositories

Teaching Effective Internal Communication

How to prepare for a 1-on-1 meeting

- Request pre-meeting email with progress, problems, next steps
- Request several slides to organize meeting discussion

How to discuss their work and problems with you and others

- Ask students to lead with high level context first
- Ask lots of questions to teach them what information is needed for you to help

How to convey they don't understand something

- Encourage them to summarize in their own words

Teaching Effective External Communication

Many different forms

- Research group discussions
- Elevator talk
- Abstract
- Paper
- Poster

Provide concrete examples for pattern matching

Start early and iterate collaboratively

- Focus on high-level idea and organization first
- Gradually get into more details
- Make it clear what level of feedback you're providing

Teaching Effective External Communication

Discuss and practice communication norms

- Express enthusiasm
- Provide context
- Focus on facts, data, and concrete steps
- Hear (and provide) feedback as suggestions for improvement of the research

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Characteristics of Good Mentors

1

Have positive attitude towards students and research

2

Have positive personality characteristics

- Humor, honesty, patience, empathy, flexibility

3

Nurture confidence, self-sufficiency, independence, self-reliance, and initiative-taking in students

How to Be a Good Mentor

- Take interest in student welfare
- Provide frequent and constructive feedback about progress
- Give students the chance to propose next steps or figure something out on their own
- Be willing to revise projects based on student skills or help them develop needed skills
- Immerse the students in your research environment
- Treat students as collaborators and respect their insights and contributions
- Do professional and career mentoring

Do Professional and Career Mentoring

- Explain the conference and publication process
- Explain the graduate school options
- Explain the graduate school application process
- Introduce them to fellow colleagues
- Discuss their career options
- Talk about your career path

Exhibit Good Interaction Styles

- Be patient
- Practice active listening
- Ask questions
- Check in for understanding
- Help plan next steps at every meeting
- Provide constructive critique
- Give praise and positive feedback!

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References – Undergraduate Research

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- Entering Research: A Curriculum to Support Undergraduate and Graduate Research Trainees by Branchaw, Butz, Smith
- Center for the Improvement of Mentored Experiences in Research
  - https://cimerproject.org/
- National Mentoring Resource Center
  - https://nationalmentoringresourcecenter.org/index.php

Have Fun and Realize You're Having a Huge Impact on Students' Lives!

- Show your enthusiasm for research and for them
- Celebrate successes and empathize with challenges
- Be okay with them not choosing a research path