HYBRID SIMULATION OF A SCIENTIFIC CONFERENCE: INQUIRY-BASED LEARNING TO ENABLE MASTER'S DEGREE STUDENTS TO ACQUIRE RESEARCH SKILLS

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ABSTRACT

A novel course concept to enable master's degree students to acquire research skills is described as an experience report. A hybrid, inquiry-based format was developed to simulate each phase of writing and presenting a research paper at a scientific conference. Students self-organized into groups to conduct each phase of the research process to conduct a research project for a scientific topic, bionic computation. Weekly group meetings with the instructor were conducted via video conference. Students learned to formulate research questions, write abstracts, acquire experimental data and evaluate open-source libraries and tools to build their own experimental models. An in-house, mini-conference was held in person, in which each group held a presentation of their work. At the end of the semester, a retrospective was held to reflect on students' experiences and summarize the lessons they have learned. After the course, slight majority of the students stated that they could imagine writing a paper about their master's theses and taking part in a real conference.

KEYWORDS

Project-Based, Inquiry-Based, E-Learning, Research Skills, Simulation, Conference, Bionic Computation

1. INTRODUCTION

During their bachelor's degree programs, students of computer science concentrate on learning technical skills, such as programming, algorithms, databases and software engineering. Due to the rapid rate of innovation, a large portion of the specific technical facts which students learn will quickly become obsolete. Self-motivation to independently learn new problem-solving skills becomes more important after graduation.

At the master's degree level, advanced research skills are required. The ability to critically analyze problems, to find and evaluate information, perform investigations, generate and evaluate potential solutions become necessary. Upon finishing their master's theses, a few of these graduates may have the opportunity to present their research at international scientific conferences and one day to pursue a doctoral degree.

The question arises as to how best to teach these research skills. Theoretical, instructor-centered lectures in research methods may not be effective without practical applications of these techniques. A different method which has shown to be effective is inquiry-based learning with a concrete project topic. This work reports on experiences made during a master's degree course on "Bionic Computation", which simulated each phase of writing a research paper and taking part in an international scientific conference.

The following research questions were investigated:

1. To what extent can inquiry-based learning in the simulation of a scientific conference help students to learn research skills needed for graduate level-work?
2. To what degree can a scaffolding approach help reduce stress levels which result from cognitive load?
3. Could the simulation of a scientific conference increase students' motivation for scientific research?

Section 2 Related Work gives an overview of related work on teaching research skills and the use of inquiry-based learning. The organization of the course and the methods used to acquire qualitative data are described in Section 3 Methods. Section 4 discusses the results of retrospectives at the end of the course. Conclusions and plans for future research are presented in Section 5.

2. RELATED WORK

An overview of literature on research skills and inquiry-based learning are given here.

2.1 Research Skills

Although technical skills were adequate for the bachelor's level degree program, research skills are critical for success at the master's degree level. Willison et al. (2018) have developed a research skill development framework to describe incremental steps of students' autonomy when conducting research.

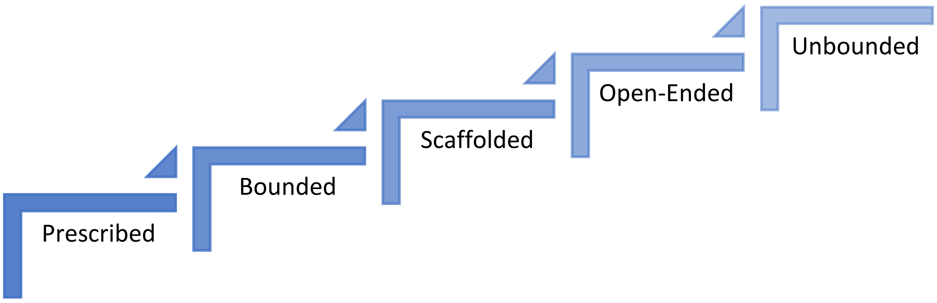

Figure 1. Research Skill Development Framework (Willison et al., 2018)

At the beginning of their bachelor's degree programs, students conduct "prescribed" research. Their work is highly structured and dependent on instructors who give explicit directions on how to use prescribed methods with pre-defined data sources. At the next level, "Bounded", instructors set boundaries to channel research within a choice of given structures and methodologies. "Scaffolded" research shapes independent research by allowing much more choice of data sources and methodologies. The instructor provides support at the beginning of the semester. Students choose from a range of approaches provided. As the semester progresses, and they begin to feel more confident, less guidance is needed. In open-ended research, students initiate their own research goals and generate their own hypotheses using self-determined criteria. In "Unbounded" research, students determine their own guidelines in accord with a specific discipline (Willison et al., 2018).

Within the Research Development Framework, students should learn the following facets of research:

1. Embark on an inquiry to determine the need for knowledge.
2. Find or generate needed information and data using an appropriate methodology.
3. Critically evaluate data and the process used to generate it.
4. Organize collected data and manage research processes.
5. Synthesize, analyze and apply new knowledge.
6. Communicate knowledge and the processes used to generate it.

Willison's models are designed to conceptualize the development path which would enable students to develop the research skills necessary to succeed in higher degree, graduate level research. Each of these research elements should be conducted with a continued awareness of ethical, social and cultural issues. He sees this as a starting point towards the development of a knowledge society (Willison, 2010).

2.2 Inquiry-Based Learning

Inquiry-based learning is an educational method in which students emulate scientific methods and practices to construct knowledge. Learners construct new knowledge by formulating hypotheses, conducting experiments to test them and then observing and evaluating the results (Pedaste et al., 2012).

Bybee developed a five-stage, inquiry-based instructional model for STEM (Science, Technology, Engineering, Math), which is based on cognitive psychology and constructivist learning theory (Bybee et al., 2006). In the first phase, „Engagement", instructors mentally engage students with question, activities or video clips. The goal is to awaken curiosity to learn more about a topic. During the second phase, "Exploration", students carry out hands-on activities to inquire about a topic, generate new hypotheses, gather data to test hypotheses, analyze and interpret the data to draw conclusions. Phase two is the most important phase of the inquiry-based experience. The third phase, “Explanation”, is more instructor directed. Students explain their understanding of concepts. Instructors provide formal definitions and correct any misunderstandings, if necessary. In the fourth phase, “Elaboration”, students apply their new understanding of concepts to conduct additional investigations, share information or apply their knowledge to other disciplines. During the final “Evaluation” phase, students assess their abilities and reflect on their learning progress (Bybee et al., 2006).

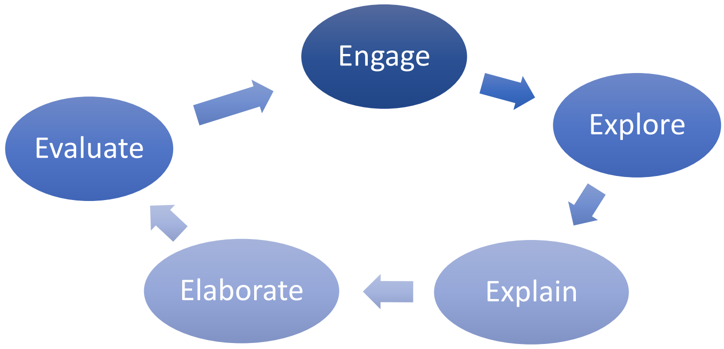

Figure 2. 5E Inquiry-based instructional model (Bybee et al., 2006)

Chu et al. (2016) described the use of a wiki in inquiry-based projects in school science education. They describe how to use a collaborative wiki to facilitate students’ co-construction of knowledge in their group project. Students reported that the use of a wiki helped to improve the quality of their group project by helping them to learn knowledge management skills to create, capture, share and transfer knowledge. Sleeter et al. (2020) applied inquiry-based learning to a graduate course in history. A hybrid, scaffolding approach was applied, with class assignments and instructor feedback. Students were assigned to create their own online learning modules. Within this pre-determined framework, they developed their own research questions, defined their audience and engaged in self-directed independent research. The freedom to explore topics of their own choosing greatly increased their intrinsic motivation.

Woolf (2017) described his experiences incorporating inquiry-based learning in a graduate course on research methods. This course was a general course taught to graduate students, without any specific alignment to concrete research interests. Because the goal of this course was to learn about the process of research itself, the lack of a specific project context may have decreased motivation. Contrary to the current recommendations of minimal interference by the instructor, instructor guidance proved crucial in this course. Especially at the beginning of the course, students experienced an initial shock that the course would not be taught as a traditional instructor-centered lecture. Students reported that the risk and uncertainty of this unfamiliar didactic method led to anxiety. Many complained of feeling overwhelmed.

The successful use of simulations in teaching math and science teachers was documented by Mikeska et al. (2021). They showed that simulations can provide practice-based spaces to facilitate argumentation-focused science discussions. Although their work was conducted at the K-12 level, it may apply to higher education.

3. METHODS

The course described in this experience report was titled “Bionic Computation” and was taught at the Computer Science Department of the Nuremberg Institute of Technology during the Spring / Summer semester of 2022.

3.1 Course Goals

The learning goals for this course can be grouped into two major categories, as shown in Table 1: subject-oriented IT-skills in Bionic Computation and research skills. Bionic Computation refers to a class of algorithms which are patterned after biological processes in nature. Evolutionary Computation mimics evolutionary processes in nature to find solutions to difficult problems (DeJong, 2016). Neural networks mimic the human brain and learn through repetitive feedback (Goodfellow, 2017). Sentiment Analysis uses computational methods to identify, extract and study affective states in subjective information (Liu, 2020). Swarm Intelligence is based on the collective behavior of decentralized, self-organized systems, such as ant colonies (Yang, 2020).

Most of the research-oriented learning goals of this course can be classified as fulfilling Level 3, "Scaffolded Research" of Willison's Research Development Framework (2010). Scaffolding aids from the educator shape independent research. Students collect appropriate data from self-selected sources using a range of methodologies. They evaluate data and inquiry processes using criteria related to the aims of the inquiry. They organize data and self-manage teams and processes. Students analyze trends in data and use discipline-specific language to demonstrate understanding from a stated perspective for a specified audience.

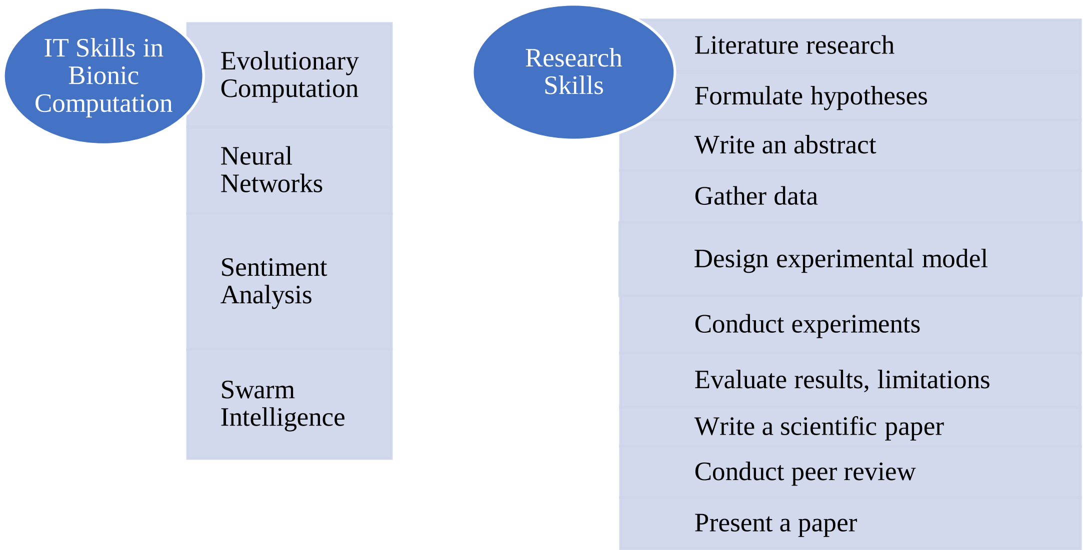

Figure 3. Learning goals in Bionic Computation and research skills

The second skill, "Formulate Hypotheses", would be classified as fulfilling Level 4 (Open-ended) of Willison's Research Development Framework (2010). Students were encouraged to apply design thinking (Brenner and Uebernickel 2016) to generate their own research questions for the topic of Bionic Computation.

The long-term goal is that after completing this course, some students should gain adequate experience to progress to the level of skills defined by Level 5 (Unbounded) of the Research Development Framework. To initiate scientific work for a PhD dissertation, students must demonstrate the ability to self-determine their own guidelines for independent research, which is in accordance with a specific discipline or context.

3.2 Course Organization

The course in Bionic Computation described in this case study simulated each phase to write and present a research paper at an international scientific conference. The course met once per week for a total of 16 weeks. This course was taught entirely in English, because international conferences are usually held in English. 24 students enrolled in the master's degree program took part in the course. Students self-organized into six teams, each with four members. Each week, teams worked on different tasks, corresponding to sequential steps in a research project. Concrete deliverables were produced every week, as listed below in Table 1.

After the initial orientation meeting with the entire class, each project team met separately once a week with the instructor. All of the teams were first required to complete one introductory level e-learning module in each of four topic groups, thus earning a "Badge of All Trades". The goal of this first level was to give students a broad overview of all four subject areas of Bionic Computation. Afterwards, each team could select one of these subject areas on their own area of emphasis. Three "expert level" e-learning modules in this chosen area of emphasis had to be completed in order to earn a "Master" level badge, such as "Master of Evolutionary

Computation" or "Master of Swarm Intelligence". Levels, points and badges have been shown to be an effective gamification method to increase student motivation (Lister, 2015).

Table 1. Research tasks and deliverables

Week	Research Task	Deliverable	Week	Research Task	Deliverable
1	Introduction	Self-organization	9	Build model	Model ready
2	Self-study e-learning units	Earn badges	10	Run experiments	Experimental results
3	Literature research	5 papers for wiki	11	Analyze results	Evaluation of results
4	Brainstorming, design thinking	Research topic	12	Write paper	Preliminary paper
5	Formulate research questions	Initial abstract	13	Peer review	Write 2 reviews
6	Design experimental model	Experimental model	14	Prepare talk	Presentation slides
7	Search for open source data	Data source	15	Conference	Hold presentation
8	Evaluate software tools	Architecture	16	Retrospective	Retrospective 4Ls

An agile project management format was used. Every week, each team presented their current deliverable to the instructor, as specified in Table 1. Research decisions made by the team, such as the choice of a project topic, had to be explained and justified. Questions and feedback were exchanged and a plan for activities to be accomplished (sprint backlog) during the next one-week sprint were agreed upon.

During the final month of course, each student team wrote an anonymous first draft of their papers using IEEE conference templates. Each team uploaded their paper to a double-blind peer review system, which was developed as a plug-in for Moodle. Each team received two anonymous papers from two other teams, which they were assigned to review anonymously. The instructor served as the third anonymous reviewer for each paper. Afterwards, each team received three anonymous reviews of their paper. It was not clear which review had been written by other students or which had been written by the instructor. Finally, each team revised their papers to incorporate the criticisms addressed in the reviews and submitted their final, camera-ready papers.

At the end of the semester, an in-person, in-house "scientific conference" was held. The conference was organized as two sessions of three papers each. Each team held a presentation of their paper to the rest of the class. During the break between sessions, posters which were displayed on Smart Boards gave students a chance to discuss their work. At the end of the conference, a "best paper award" was voted on by the students.

3.3 Data Collection

3.3.1 Project Topics

Student teams were allowed to select their own project topic. The main restriction was that the project had to focus on a practical application of one Bionic Computation method. The project topics chosen by the students and the corresponding methods of Bionic Computation are shown below in Table 2.

Table 2. List of project topics

Project Topic	Bionic Computation Method
Detection of hostility in open-source development communities	Sentiment Analysis
Generation of visitation plans for tourists in European cities	Ant Colony Optimization
Generation of fashion designs	Neural Network
Influence of cultural dimensions on authors' tweets about the pandemic	Sentiment Analysis
Maritime collision avoidance	Particle Swarm Optimization
Optimization of government administration processes	Evolutionary Computation

3.3.2 Course Retrospective

On the final day of class, a retrospective was held to give students a chance to reflect on what they had learned. An agile project management technique called the 4Ls method (Gottesdiener, 2010) was slightly modified to gather qualitative feedback from the students. Note: Gottesdiener designates the fourth category as "Long for", which proved confusing to German students. Each student was given sticky notes, one in each color and asked to write down one experience or opinion which corresponds to each category:

- Like: What went well on this project?

- Lack: What did you miss? What did not go well?
- Learn: What did you learn on this project?
- Long game: What will you do differently on your next project, based on what your learned here?

Students were given a few minutes to fill out their notes in private, in order to avoid influences from other group members. Next, each student went up to the white board, placed each note in the appropriate group and explained each experience or opinion. Afterwards, students clustered similar notes to form larger groups. Each cluster was then discussed in more detail by the entire class.

3.3.3 Anonymous Online Evaluation

At the end of the semester, students were asked to fill out an anonymous online evaluation form. Questions were similar to the research questions of this paper. Possible answers were “agree”, “neutral” and “disagree”.

1. Did this class format help you to learn research skills?
2. Did you find the e-learning modules at the beginning helpful?
3. Could you imagine writing a paper and taking part in a conference?

4. RESULTS

4.1 General Results: Project Topics

Because students had the freedom to suggest project topics of their own choosing related to bionic computation, a variety of extremely original topics were generated, as shown in Table 2. This wide diversity of application areas could never have been generated by the instructor alone. One of the topics, generative fashion design, required such a high amount of computational resources that additional computing power had to be purchased from Google Colab. Another topic which students proposed, avoidance of maritime collisions, was initially judged as too difficult by the instructor. Due to the personal interest of the team members in this subject, they decided that were willing to put in additional effort to explore this research project anyway. The student team which won the “Best Paper Award” submitted their paper to a conference and were able to participate online. Due to a lack of funding, they were not able to travel in person (Dobler et. al 2022).

4.2 Retrospective according to 4Ls Method

At the end of the semester, a retrospective according to the 4Ls Method (Gottesdiener, 2010) was conducted. The most commonly voiced opinions, ranked by their frequency of expression are summarized in Table 3.

Table 3. Results of the 4Ls retrospective

Like	Lack	Learn	Long game
Freedom to choose topic	Direction at beginning	Literature review	Document every step
Self-organization	More documentation	Scientific research	Look at related work
Hybrid e-learning	Organization of wiki	How to write a review	Structure problems more
Weekly meetings, tasks	Started development late	How to write a paper	Order steps to be done
Deep dive into one topic	Prior knowledge of NNs	Different approaches	Smaller teams
Peer review	ML as prerequisite	IEEE paper standards	Structure literature
Write a conference paper	No experience w Python	Use citation tools	Start writing earlier

Students stated that at the beginning of the semester, the unusual course format led to uneasiness. They experienced doubts that they did not know exactly what to do to achieve a good grade. Some students felt that they lacked the prerequisite programming skills to implement the experimental models they had designed. As the semester progressed, however, most students came to appreciate the freedom to propose and then explore a self-chosen topic. Some teams reported spending much more time than planned on this course, to the detriment of their other courses. The freedom to self-organize also resulted in the inherent challenge in managing a project with four group members. Although some groups were extremely well-organized and finished early, other groups underestimated the amount of effort required to write a scientific paper.

4.3 Results from the Online Questionnaire

After the course, students were asked to fill out an anonymous evaluation form as show in Table 4. A majority of the respondents answered that the class format of a simulated conference helped them to learn research skills. The two who responded neutrally wrote in the comments that they already possessed these skills. The two who did not like the class format wrote that they would have preferred a classic seminar, with only a presentation and a paper. A majority of the students reported that they found the e-learning modules at the beginning of the semester helpful. The two who disagreed stated that they were already familiar with the topics. A slight majority (15) of the students answered that after this course, they could imagine writing a paper and taking part in an actual scientific conference. Five were unsure and four disagreed.

Table 4. Results of the online questionnaire

Online Questions	Agree	Neutral	Disagree
1. Did this class format help you to learn research skills?	20	2	2
2. Did you find the e-learning modules at the beginning helpful?	22	0	2
3. Could you imagine writing a paper and taking part in a conference?	15	5	4

4.4 Classification of Skill Levels According to Research Skills Development Framework

In the opinion of the instructor, students at the end of this course demonstrated capabilities which would fulfill Level 3, “Scaffolded Research”, of Willison’s Research Development Framework (2018). The initial introduction by the instructor and the e-learning modules provided scaffolds to give students more start at the beginning of the semester. Students demonstrated that they could search for relevant literature in online databases and later gather or generate their own appropriate experimental data from self-selected sources. They designed and built their own experimental models to generate results, applying algorithms of Bionic Computation for their inquiries. They learned to organize their data, self-managed their own teams and processes using cloud-based collaboration software. They learned to use discipline-specific language to write and present a scientific paper for a specified audience. Some of the work accomplished would actually fulfill Level 4 “Student-Initiated” of Willison’s Research Development Framework (2018). Students demonstrated the ability to apply creative thinking techniques to generate their own ideas for project topics and learned to generate their own research questions and hypotheses to explore these topics. Student-Initiated research skills on Level 4 should be of great help to write a master’s thesis and would also be necessary for a PhD dissertation.

4.5 Limitations

The results reported in this case study are subject to a number of limitations. First, due to the nature of a case study, results can not necessarily be replicated uniformly. The number of participants in this course (24), is too small for any meaningful statistical analysis. The students who participated in this course are not necessarily representative for all master’s students of computer science. Because this was an elective course self-selection among those who chose this course could have biased these results. Students who prefer traditional lectures with exams or those who were not confident of their English skills would have chosen different courses.

5. CONCLUSIONS

In closing, a return to the initial research questions is warranted:

1. To what extent can inquiry-based learning in the simulation of a scientific conference help students to learn research skills needed for graduate-level work?

A majority (20 of 24) students reported that the course format simulating a scientific conference was helpful to learn the research. Through inquiry-based learning, they demonstrated skills which could be attributed to Level 3 and 4 of Willison’s Research Skill Development Framework (2018). This first research question can thus be answered as mostly true.

2. To what degree can a scaffolding approach help reduce stress levels which result from cognitive load?

Although at the beginning of the course some students expressed feeling unsure, a majority (22 of 24) stated that the initial scaffolding of e-learning modules, combined with the weekly schedule of tasks and deliverables helped them to gain confidence. The answer to this second research question is mostly true.

3. Could the simulation of a scientific conference increase students' motivation for scientific research?

Slightly more than half (15 of 24) of the students reported that the course format of simulating a scientific conference increased their motivation to one day submit a paper and to participate in an international conference. The answer to this third research question is thus slightly more true than untrue.

The knowledge gap between the programming skills adequate for a bachelor's degree level and the research skills necessary for graduate level courses can be bridged by inquiry-based learning. This work has shown that a course structured as a simulation of a scientific conference can help motivate students to acquire the research skills vital for graduate work, such as writing a master's thesis and submitting a paper to a scientific conference.

The conference simulation model presented in this case study could be adapted to other subject areas at the master's degree level. By actively practicing research skills during the master's degree, the hope is that more graduates could be motivated to begin a PhD program.

Further work on this subject will include writing a grant proposal to obtain funding to send the team which wins the "Best Paper Award" to travel an international scientific conference. The chance to participate in person at an actual scientific conference will hopefully further increase student motivation for research.

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