INQUIRY, THE SCIENTIFIC TOOL FOR ALL INSTRUCTIONAL METHODOLOGIES

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ABSTRACT

The Inquiry based learning, in the class of active learning is receiving lot of attention these days to an extent that, it is a major theme in national science education reforms: “Science education for All in America”. Hence an attempt is made in this study to measure the effectiveness of inquiry-based learning in the field of engineering specially applied to Microprocessors and Microcontrollers course. Jubin simulator was used as an ICT tool for implementation. This paper discusses the process by which the inquiry questions are designed. These questions along with the carefully defined procedure helped the students to do self-discovery of the concept called stack, which is associated with all programming. Results showed that inquiry is positively linked with outcomes when it integrates teacher guidance, and negatively when the inquiry is not designed effectively. It also shows that optimal learning is achieved when technology is blended with systematically designed inquiry learning instructional methodology.

KEYWORDS

Inquiry, simulator, Stack, Standards: 2, 5, 6, 7, 8

INTRODUCTION

Project is an important instrument to evaluate students to examine if they have developed critical thinking skills for their career success. When students do their project, if something fails, they should question themselves. There is some evidence regarding the Generation Z students that, they generally lacking in critical thinking skills as they spend most of their time in gadgets (Mancall-Bitel, 2019) and have no time to reckon with. Now and then simple position change makes their project working, but the students will not have any clue, why it worked and do not want to dig too deep. Such students certainly need inquiry questions by the teacher to drive them towards learning from their day one. Inquiry may be referred to as a technique that encourages students to discover or construct information by themselves instead of having teachers directly reveal the information (Uno, 1999). However, making inquiry questions is an art, it needs exceptionally competent teacher to design. This paper presents the process by which the given inquiry learning is designed to understand the concept of stack in Microprocessor and microcontrollers course. This paper has been divided into five parts, where the second part reviews relevant background on active learning, Inquiry Based Learning (IBL), Process Oriented Guided Inquiry Learning (POGIL) and compares them to other forms of active learning. Third part explains the development of inquiry questions with an example both for conceptual level understanding and higher cognition level in the bloom’s taxonomy. The section 4 relates the work to CDIO standard, and the last part analyses the feedback received by the students and discusses the results.

LITERATURE REVIEW

Active learning is a technique of teaching in which students actively engage with course material through conversations, problem solving, case studies, role plays, and other ways. Compared to passive methods like lectures, active learning approaches lay more responsibility on the learner, although in an active learning setting, instructor direction is still essential. Activities that promote active learning can last for a few minutes, an entire class period, or even several class periods (Felder & Brent, 2009). Among all active learning techniques collaborative learning (Hiltz, 1988). Concept mapping (Davies, 2011), scavenger hunt (Stark, Opuda, McElfresh, & Kauffroath, 2021), Role playing (M.D., 2009), Jigsaw technique (Adams, 2013) online discussion boards (Covelli, 2017), flipped classroom (Tucker, 2012), inquiry learning (Pedaste, et al., 2015), inquiry plays a special role as it leads the learners to construct the knowledge themselves, instead of having teachers directly reveal the information. Construction comes from the guided questions from instructor or unguided questions from students. The keystone for the construction of such knowledge comes from the answers to such questions. However, the method used to construct the keystones depend on the constructor of the questions (Reiff, Harwood, & Phillipson, 2002). This infers that the volume and type of knowledge that can be constructed in an engineering inquiry classroom would depend on the questioning skills of science teachers. Hence the methodology starts with the way to frame such questions, which makes them to retain the knowledge they earned for long time.

Independent learners will be more driven to find solutions to the most difficult problems encountered by an organisation or group since they are aware that knowledge acquisition never stops. Students actively participate in their own learning process in an inquiry-led learning style. In the end, this results in a feeling of independence that motivates pupils to keep asking questions and looking for solutions long after class has ended (Hwang & Chang, 2011). IBL is generally classified into 4 types which are (i) The Structured Inquiry Approach, (ii) The Open-Ended Inquiry Approach, (iii) The Problem-Based Inquiry Approach and (iv) The Guided Inquiry Approach. A good inquiry-based instruction should not only develop conceptual understanding, but also more mature epistemic beliefs (Nitsche, Mathis, & O'Neill, 2022) and one such beliefs include, that knowledge is based on empirical evidence whose meaning is influenced by the models/theories which scientists employ (Pluta, Chinn, & Duncan, 2011).

IBL encourages students to think critically and analytically. While analytical thinking assisted students to establish the similarities and differences in variables and tendencies in data, critical thinking aided them in determining the reason why a variable changed and how that change affected other variables. Also, (Duran & Dökme, 2016), demonstrated that IBL, leads to lifelong learning by focusing on making the students to ask questions, critical thinkers, and problem solvers. POGIL also works in a similar way except for group setting with different roles assigned to each student (N.M.Masoodhu Banu, 2017) where students help each other. The role of the teacher as a facilitator within the model of inquiry as opposed to a more traditional didactic teaching approach (Dana, Thomas, & Boynton, 2011) contributed to students' active engagement in all the inquiry classroom settings. Some learners learn better with experimental setting and the authors (Zannin, Lima, & Pinto, 2021) have combined the inquiry learning with the remote lab settings, however this lacked instructor's direct interaction. Also, all the literature mainly delas with the design for inferences rather than instructional design methodology. Hence, this paper attempts to syndicate the benefit of practice-oriented learning and guided inquiry learning for optimal learning along with microlevel instructional design.

METHODOLOGY

The study employed a controlled design in which half the participants went through normal lecture classes with clear diagrammatic representation of the topic being addressed as well as explanation through simulation. The other half (experimental group) went through the same simulation activity performed by students in group with IBL to construct the concept themselves. The activity for the teacher is to develop a worksheet and design a list of outcome questions which will be able to evaluate engineering skills sets attained by the students. The activity of the student is to record the observations (all general registers value) and the stack pointer and program counter in specific to understand the program flow. They also must answer the questions listed in the outcomes. The number of questions answered by the students were used as performance index, which indirectly measures their capability as a reflective thinking person. The learning material (worksheet) that is implemented in this research have passed the validity test by presenting and testing it with the other teachers. As teachers play the most influential role in inquiry learning (Grandy & Duschl, 2007), some beginning teachers were also included in this study, but to evaluate their skills in designing the inquiry question. i.e., after they were taught to answer the worksheet designed by senior teachers, they were asked to design such inquiry worksheets for some other concepts and the outcome was evaluated with the same set of students.

DESIGN

The students of Biomedical Engineering department were considered for this research. Generally, they have an idea that programming is not required for Biomedical Engineers. Hence it is basic requirement for the teachers to kindle interest in learning by making the learning process easy such that it retains in their memory for long time. The research uses simulator-based approach as it is difficult to use the development board on daily basis. Jubin simulator (an open-source simulator) for 8085 microprocessor was chosen for this. First an appropriate code snippet was designed for explaining the concept of stack. Then a clear step by step process has been developed to design inquiry questions. These questions along with step-by-step operation of Jubin simulator was given to students to self-discover the concept of stack. The whole process will be like guided investigation.

The students were allowed to choose their mates or remain them as individual as the core point of this research is to kindle their thought process and not cooperative learning.

1. Teachers develop questions in such a way that students get curiosity to answer.
2. Supplement the questions with some action, may be to read a journal paper or book chapter with pointers to read particular section. More than this if it can be supplemented with step-by-step procedure simulation activity, the inquiry kindles the curiosity for learning. In class activity is best mode as, students' needs the access to the faculty. Students will have to construct after the end of this class. Sufficient time needs to be given for such activity
3. Check everyone's construction for meaningfulness. If found to be valid, make the students present what they've learned as communicating what they understood is better than just understanding for themselves.
4. Request students to reflect on how the inquiry questions given by the teacher worked on and what did not. Reflection is key as it gives the faculty a guidance to correct them if majority could not understand the concept by the whole process. Metacognition—thinking about thinking can work this way. Also, this makes the students focus on how they learned in addition to what they learned. This makes the students create questions themselves for understanding factual concepts.

Instance

The students of 2nd year Biomedical Engineering were considered for the activity and the course considered was Microprocessor and Microcontrollers. Total 60 students were considered, where 30 of them put in control group and the rest 30 in experimental group. Though many of the concepts were taught with simulator, the concept of PUSH and POP were taught with inquiry learning. In case of simulator-based learning, the teacher executed every step and asked the students what happened at each point, but with the guidance of asking them to look at memory or registers appropriately. Though they understood at that point of time, they did not apply in general for all the concepts taught later. Hence it is decided to have an IBL to make them to think themselves to arrive at the answers to construct the knowledge. The following inquiry questions were framed as in Table 1 to focus the student's attention to one key topic called stack.

Port programming with SP and PUSH POP concept

1. Start the debugging session.
2. Observe the stack pointer value before execution and make note of it
3. Open memory window I: observed SP value
4. After executing each line record your observation in the table 1 with columns titled registers and stack pointer

Table 1 Guided Inquiry questions for the given code snippet

S.No	Programming step	Observation	Value at Stack pointer and program counter	Value at the stack pointer memory
1	Execute the first three instructions one by one and note the Accumulator and other register values			
2	After the execution of first three instruction. Note the value of stack pointer here			
3	Observe the value of PC after the CALL instruction, note the value of stack pointer too			
4	After each PUSH, POP instruction, observe the changes in SP and its contents			
5	What is the operation taking place up to STA C053			
6	With 2 POP instructions, what happens to SP and its contents			
7	After RET instruction where the program jumps to?			
8	What was the function done by the CALL subroutine?			

CDIO CONNECTIONS

Learning outcomes are mandatory for any courses designed in the curricula. Similarly, each concept explained also should have its own learning outcomes and are listed in Table 2. CDIO Syllabus lists various outcomes like disciplinary, interpersonal and system/product building skills. The learning outcomes acquired through IBL and hence disciplinary skills as discussed in the CDIO standards are listed in the below Table 3. Though the present work IBL does not relate to the design experience directly, the skill set acquired will help the learners in future when they design an embedded system. Embedded systems need compact memory and hence the most appropriate value for the stack size needs to be designed. Since the students know how PUSH/POP affects, they will design their system with care. If any issues come after their design during prototype development, they have solid analytical knowledge about the concept stack and hence they will have rich design and

Table 2 Questions on Learning outcomes

S.No	Outcome Questions
1	What did you learn about PUSH and POP From where to where the content is pushed. from where to where the content is popped Is there any order in which you need to do PUSH, POP operation?
2	What does CALL instruction do? What happens to PC and what happens to SP?
3	What does RET do? What happens to PC and SP?
4	Change the order of POP instructions and observe what happens to the add instruction results now? So justify if we can interchange POP Ing and PUSH ing order?
5	How the stack pointer changes with respect to each PUSH and POP instruction
6	Summarize the entire process with respect to CALL instruction

Table 1 Disciplinary skill set addressed according to CDIO Syllabus.

S.No	Outcome/Competency Questions	Skills acquired and CDIO syllabus outcomes
1	What did you learn about PUSH and POP From where to where the content is pushed. from where to where the content is popped Is there any order in which you need to do PUSH, POP operation?	Engineering reasoning and problem solving (2.1)
2	What does CALL instruction do? What happens to PC and what happens to SP?	Curiosity 2.4.6
3	What does RET do? What happens to PC and SP? What is the difference you observed between CALL and RET	Critical thinking 2.4.4
5	Relate all the above facts to arrive at how the stack works. What can be the programming mistakes?	Thinking holistically (2.3.1)

implement experience. (CDIO Standard 5 Design-Implement Experiences.) The study also addresses the Standard 6 (engineering workspace), because without such a space, a hands-on learning leading to self-discovery of knowledge would not be possible. The Standard 7 (Integrated Learning Experiences) is also addressed due to the nature of the model i.e., inquiry learning unsurprisingly experiences the students through interpersonal skills by way of discussion. Finally, as, Inquiry learning gives no scope for passive learning, it can be said that, the proposed work also addresses Standard 8 (Active Learning)

RESULTS AND DISCUSSIONS

Through this research, guided IBL material was developed and implemented to improve student's engineering programming skills in terms of attention to details, thinking and retaining information. Assessment is needed in some form to validate the work and hence the questions were classified for all the three skills mentioned above. Table 1 questions were mapped to skill set 1, and Table 2 questions were mapped to skill set 2. After the inquiry class questions related PUSH, POP operations in general, the application of it for other scenarios were given. This was used to assess their knowledge application and, hence retaining information. Hence the response of every individual student for the above worksheet was evaluated. The evaluation results are given in Table 4. In both groups almost 90 % of the students answered them correctly for Table 1 questions. However, for table 2 questions, 90 % response from experimental group and only 55% response from the control group. This is due to the instructional delivery difference. Teaching the concept of stack using passive lectures takes less time in comparison. However, delivering the content through such inquiry worksheet makes them pay attention also to other details. Before they learn instructions like mov, mvi etc and then forget. But here the learning is carried forward in the process of understanding the stack concept and the repetition in learning leads to improved retention of the knowledge. However, in teacher led delivery it is not so, as they grab only the comprehension i.e., stack increases or decreases by 2 or 1 byte. This helps the students to extend their thinking from the concrete and factual to the analytical.

Table 2 Evaluation Results

S.No	Item	Experimental/ treatment group		Control group	
		In numbers	In percentage	In Numbers	In percentage
1	No of students answered questions in Table 1	27	90	27	90
2	No of students answered questions answered both in Table 1 and Table 2 except question number 6	27	90	16	55
3	No of students answered all the questions in table 1 and table 2	21	70	9	30
4	No of students just operated/not operated the Jubin Sim	3	10	3	10

Unless they think, they could not construct the concept. It can be seen from the Table 4 results in row 3 that, while 70 % of the students from experimental group (IBL) were able to construct the knowledge about stack pointers, only 30 % of the students from the control group could do the same. The inquiry worksheet blended with technology paved the way for the experimental group to construct the concept themselves. This ability of self-constructing the knowledge is one of the prerequisites for making oneself dependable expertise. Not only that, but it also teaches the types of programming mistakes and hence the consequences. Students self-trial in changing the order of PUSH and POP and hence the answer to the 4th question in Table 2 addresses such mistakes. When the same concept was taught for the microcontroller 8051, students immediately captured and could solve many problems given in the class. Thus, the designed activity avoids student's mentality of understanding the concept only with words and sentences and limiting the concept only to the specific field. If concept construction comes through their own self, through such learning, students will realize the importance of the concept they learnt, like stack in this research, and will be able to apply to other applications, like embedded system project implementation. The retention of the knowledge to apply whenever needed can be related to long time memory.

Evaluation of the student's worksheet showed that there were three kinds of learners. Though the questions had one clear answer some did wrong because they were not knowing the operation of the tool sincerely. They lacked interest and hence no motivation to learn. Such kind of learners need counselling for motivation. The next group answered the observatory questions clearly, but not able to answer the learning outcome questions. The reason is that the concept of knowledge construction through appropriate thought process, needs some reasoning ability to connect the dots to get the result. The third group did well in all respect. Even though the second group did not answer the outcome questions, latter they were able to grab the concept by repeatedly giving new problems on the same context, i.e., they could convert their factual knowledge to analytical knowledge over the period. Overall, the reflection is in experimental group, 90% of the students could identify the operation of stack, while programming and its usage. and answered all the inquiry questions (row 2, evaluation results in table 4) what they observed in the simulator but some from the 90% (row 3, evaluation results in table 4) could not construct the concept by linking all together, though indirect linking questions were also given. The remaining 10 % students could not even operate the simulator either because they do not have interest, or they did not understand. Their attention in the classes and their involvement showed that they did not have interest to learn.

However, the success of inquiry-based instruction lies hugely with teacher's perception motivation and above all competency in creating such questions. Hence teachers were asked to prepare inquiry questions with same simulator for teaching other concepts like differentiating between return from interrupt and return from subroutine. 75 % of the young faculty were not able to design the code fragment for teaching this concept. They knew to use the technology i.e., the simulator here and can search and teach an example for subroutine and interrupt. But could not apply their knowledge in designing an appropriate small piece of code for teaching the same. When the same set of students were involved to evaluate beginning teacher's worksheet, meaningful knowledge construction did not come. This is because they did not find linking questions to provide meaningful reflection or knowledge construction. Hence it is concluded that, not only competency but also a skill set of integrating the technology with the content is essential for IBL. Also, the same topic was delivered without the simulator, but with IBL(framing of question was done differently), the generation Z learners did not find It quite interesting and focussed learning was not possible. It was found that, only 50% of the students could connect the dots to arrive at the solution. This gives clear evidence that learning is maximized when technology is integrated with IBL

CONCLUSION

This study attempted to evaluate the practicality of integrating the technology with the inquiry learning. The study results show that, IBL improves the skill set like attention to details, reasoning, and memory retention. However, it comes with the cost in the form of additional effort by the teacher, i.e., it is efficient only when proper content in the form of questions is integrated with technology. And the content creation needs interest along with time and competency of the faculty. The study results also show that, blending technology with inquiry learning leads better learning than without technology.

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BIOGRAPHICAL INFORMATION

N. M. Masoodhu Banu, Ph.D, graduated from Thiagarajar College of Engineering Madurai, obtained her M.E from College of Engineering Guindy, Chennai and doctorate from Anna University Chennai. She has worked in Indian Space Research Organization Bangalore, India from 1999 to 2000 and in Motorola India Electronics Ltd Bangalore from 2000 to 2008. During her tenure in Motorola, she has worked on audio and video codecs implementation on Texas processor and also on various real time operating systems, based system implementation, where all these algorithms went into various versions of Motorola mobile. Being an Industry person, knows the gap between Engineering Education standard and Industry requirement. Hence currently she has started focusing her scholarly activities on innovative pedagogy and curriculum development. She is a creative thinker in designing instructional methodology to suit the current generation student's needs. A highly passionate, hardworking teacher who wants to teach the students in multiple dimensions. Hence a lifelong learner who keeps updating with current technology and follow this to the core. She believes in the research which goes hand in hand with academics. Her research interest spans across Embedded signal processing, Artificial intelligence and neural networks et in addition to pedagogy.

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