Research Framework and Design of Incorporation of Conversational Agent in Mathematics Learning

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Abstract. Mathematics is a fundamental core subject of STEM education. However, mathematics concepts are abstract and many students having difficulties to understand it. Moreover, some students are lack of confident, having negative feelings towards mathematics, feel not relax and cannot focus in mathematics class. Furthermore, university classes usually are large scale that make individualized assistance difficult to achieve. Conversational agents (CA), an automated computer software, allow users to interact with it through human language dialogues may implement into education to support the teaching and learning process. Nonetheless, CA still in the beginning stage to implement in education domain where the CA research in this domain, especially mathematics subject, is found scarce. This study is to incorporate CA into undergraduate mathematics learning. This paper is to present the research framework based on Vygotsky's ideas and research design with mixed-methods using multi-instruments.

Keywords: Conversational-based agent · edubot · Vygotsky theory · scaffolding

1 Introduction

Education plays an important and central role in any country to pursuit of the country's economic growth as well as national development. In many countries, Science, Technology, Engineering, and Mathematics (STEM) education is an important agenda at which this education is aims to produce students whose equipped with knowledge, skills, and values in the STEM fields.

Meanwhile, mathematics is the key subject to the other three STEM subjects as mastering it may enable students to understand the concepts of other disciplines better [1]. However, mathematics concepts are abstract where the famous mathematician Poincaré (1908/52) had already in the last century described impressively on students' difficulties to understand mathematical ideas [2]. Nevertheless, some students are lack of confident or having un-pleasure or negative feeling towards mathematics and anxiety when confronting mathematics problems. Consequently, they feel not relax in class, tend to lost focus and cannot perform well in any mathematics assessment.

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In the learning process, open-ended question and answer sessions between lecturer and student, and reviewing students' solutions to the given problem could definitely produce better learning outcomes. However, the factors like the large size of university classes, the lecturer have syllabus to cover in limited duration of each class, some introverted undergraduate prefer not to ask questions in class or to get consultation from the instructors in their office, and etc., make the effective learning and engagement difficult to achieve.

Many studies shown that there is a significant relationship between students' attitude towards mathematics learning and their mathematics' academic achievement [3–8]. Furthermore, the lack of personalized assistance may decrease the undergraduate's satisfaction, weaken the learning outcomes and increase the dropout rate [9–11].

On the other hand, technology is continuously growing to simplify and amplify our daily life. In spite of many different audio-visual technologies, text-based chat applications and instant messaging are still popular, increase exponentially and remain primary preferred by people. In addition, the usage of conversational agents (CA) (also called chatbots) are a recent ubiquitous trend apply in almost every industry that integrate as personal assistants, technical support helpers, medical or health interventions and etc. CA are automated computer programs allow human users to interact with it through auditory or textual natural language conversations.

The history of chatbots started since 1960's, but the chatbots developing activity has become popular after the annual contest, Loebner Prize Competition has introduced by Dr. Hugh Loebner, the National Science Foundation, and the Sloan Foundation in 1991. Although CA have gained popularity and widely used in many fields, but the result gleaned from literature reviews done by many studies shown that its implementation in education is found rather scarce [12–15]. According to Chatbot's Magazine [16], chatbots are still in the beginning stage to expand and will expand into more fields, including education.

Although the implementation of CAs in education is scanty, but for those applied in education were focusing on the domain of language learning, medical education, economics, and programming [14, 15]. Furthermore, the application in other than these domains are not widely spread at which CAs are still in the introductory stage [17]. In addition, its implementation in mathematics education is found very limited especially in the research country. Besides, Stathakarou et al. [18] mentioned that there are limited pedagogical examples.

As summarise in Winkler and Söllner [15], there are four main advantages contribute to the increasing usage of CA. First, CA may save customer service costs at which the implementation may replace almost all human assistants. Second, CA may increase user satisfaction as CA are available 24/7, hence, the responding time is shortening. Third, CA proactively interact with its users by replying the exact information as requested by user in comparison to websites and apps, and human assistance. Forth, CA is a good business analysis tool due to the conversations history could be analysed automatically. In view of the second and the third advantages, CA could be a great tool to implement in education settings as well.

Additionally, the instant information retrieval facility of CA is another potential advantage for it to integrate in education domain. Furthermore, Chatbot's Magazine

[16] presented that CAs could change education at which it presents the content and problems by increasing the level of difficulties and different level of learners control the learning pace without feeling discourage by other learners and embrace as compared in the traditional classroom learning.

Henceforth, this project is to incorporate CA into undergraduate mathematics learning with three main objectives. First, it is to investigate the effects of incorporating CA on students' mathematics achievement. Second, it is to investigate the effects of incorporating CA on students' attitude towards mathematics. Last but not least, it is to study students' perceptions of the use of CA in learning mathematics.

This study is still an on-going project, thus, this paper is to discuss the research framework and research design of this project with the aim to give future researchers some insight to bring CAs into mathematics education in order to fill important research gaps.

2 Research Approach

There are various teaching and learning approaches and theories in education implemented by different instructors to cater the different learning style of students and to achieve different learning goals. A learning theory called constructivism has emerged in education in the last twenty-five years that gives the most influences on the practice of education [19]. Constructivism is a theory of knowledge describes how learning happens or the way learners generate the knowledge during the learning process. According to constructivist learning theorists, learners' experience cannot be separated from the learning process. Constructivism, also is the psychology of learning, is initiated by the works of Jean Piaget and Lev Vygotsky.

In this study, the theory by Lev Vygotsky is applied. Lev Vygotsky (1896–1934) is a Russian who are not only a psychologist but a philosopher in the 1930s. Vygotskian theory emphasis the fundamental role of social interaction in the development of cognition [20] which consists of three major themes, namely social interaction, the More Knowledgeable Other (MKO) and the Zone of Proximal Development (ZPD).

Vygotsky believes that much important learning by the learner occurs through social interaction with a skillful tutor (often the teacher or parent) [20] or MKO. The MKO provides collaborative dialogue at which the MKO may give verbal instructions or model behaviors (demonstration) to the learner. The learner internalizes the information and using it as guide for his own performance after he seeks to understand these instructions or actions.

More Knowledgeable Other (MKO), as to its term, refers to someone who has more knowledge or skill or experience or better understanding or higher ability than the learner. Although MKO is most often refer as a teacher, parent or older adult but it could refer as a peer or older. However, in this technology era, the electronic tools that programmed with the knowledge may play the MKO role [21].

Zone of Proximal Development (ZPD) is a principle integrally from MKO. Vygotsky defines ZPD as "*the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peer*" (p. 86) [20].

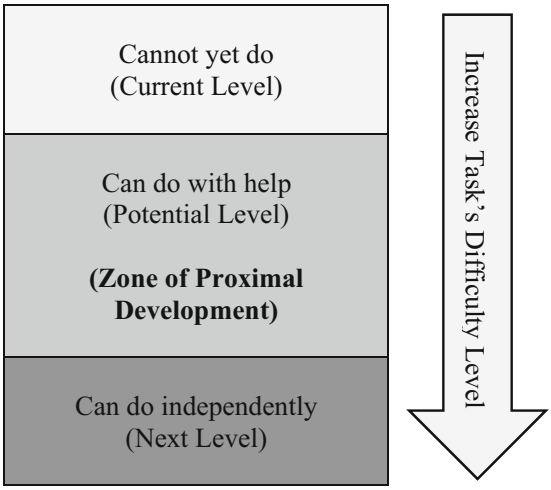

Fig. 1. Vygotsky's concept of Zone of Proximal Development (ZPD)

A learner will go through three stages when he is learning to solve the problem for the first time. At the beginning, he may not solve the problem yet ("cannot yet do"). Then, he may solve it with the assistance and guidance from MKO ("Can do with help"). Eventually, he can solve the problem independently ("Can do independently"). As defined by Vygotsky on ZPD, the stage of "cannot yet do" is refers as the current level of development of the learner, while the stage of "can do independently" is refers as the next level. Thus, ZPD is the zone to describe the transition stage from current level of development of the learner to the next level which is the stage of "Can do with help".

In the learning process, Vygotsky mentioned that it is more important to assess learner's potential level than his current level [22]. Moreover, keeping learner in his own ZPD as often as possible is the main goal of education. This is done by giving him gradually difficult problem-solving tasks where collaborative work (social interaction) with more capable other (MKO) taking place in completing the tasks (see Fig. 1). As such, guided learning (scaffolding; a term did not coin by Vygotsky but by his followers after the application of ZPD in the education contexts) within the ZPD drive learner to greater understanding or performance than working alone [23].

3 Theoritical Framework

In this project, Vygotskian theory is applied to frame the study of student mathematics learning through CA. Furthermore, the main focus is based on Vygotsky's idea on scaffolding and mediated tools, at which this study is to scaffold students in a conversational-based agent mediated learning environment in learning mathematics.

Indeed, the CA act as the MKO guided learner in the learning process within ZPD by guiding him in solving the problems that are a little more difficult than the previous

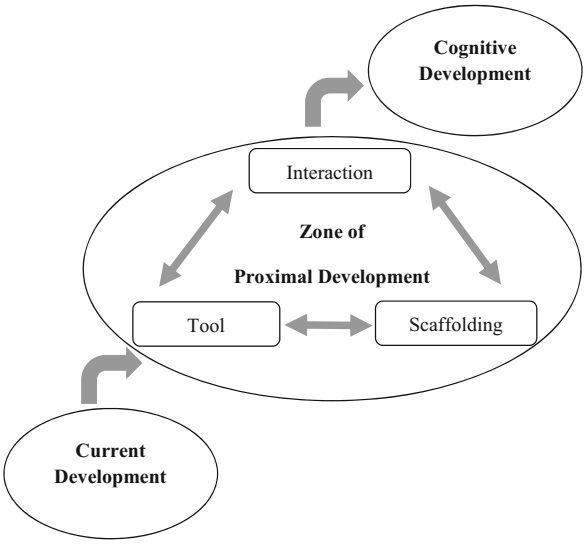

Fig. 2. Vygotskian principles that are adopted in this study

problem where the meaningful learning happens through the collaborative dialogues (social interaction) between learner and CA.

The information gleaned from literature reviews on those research that were based on Vygotsky's ideas [23–28] had provided evidence that development of knowledge is socially mediated through interaction with more competent other, with scaffolding and using tools in learning. Additionally, as discussed in Taber and Li [29], there are now very useful and many tools that can support the scaffold learning within the ZPD of each learner. Henceforth, it is belief that Vygotsky's principles can be applied this study.

Figure 2 illustrates the Vygotskian principles that are adopted in this study and it is the guide for this study as well. The content and the flow of CA was designed and developed based on this principle too. A learning process is a process to move a learner from current development stage to cognitive development stage. In the learning process, knowledge cannot be transferred from one to another. Instead, the development involves social collaboration allows learner construct his own knowledge while the instructor or teacher or more competence other plays the role like facilitator by provides guidance. Vygotsky emphasized that learning occurs when learner interact socially with the experienced teacher or more competence other who act as scaffolder assists learner to construct knowledge and meaning. In addition, the presence of mediated tools is essential to achieve to cognitive development stage.

In other words, learner actually actively constructing the new information (knowledge) based on his own ideas, experiences or belief in order to fit them into his cognitive framework. When the task is getting difficult to complete by his own in this knowledge acquiring process, he will seek assistance from MKO and the task is complete through social interaction and collaboration with MKO. Therefore, the ability to complete the task with the collaboration now, will enable learner to perform it independently in the future.

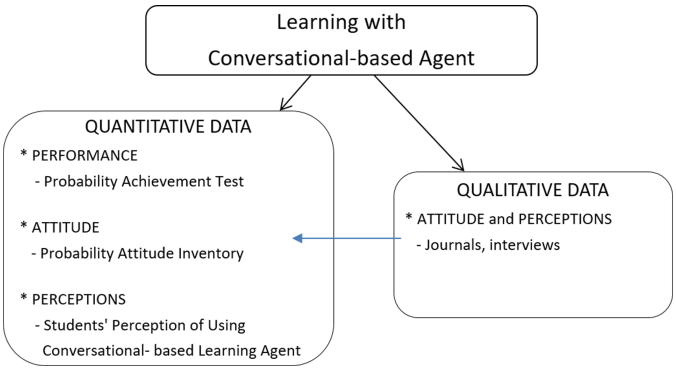

Fig. 3. Research framework

4 Research Framework

A mixed-method approach, namely a method that consists of both quantitative and qualitative methods, with multi-instruments is adopted in this study in order to provide the scope and depth for the study [30]. Hence, both quantitative and qualitative data were collected to ensure the triangulation of evidence. Subsequently, the reliability, validity and credibility of data and the process of collecting the data may increase, besides, these type of collected data may complement each other [30–32].

In addition, the quasi-experimental research design was conducted due to the study was carried out after the groups have been formed. Moreover, the convenient sampling was adopted attributable to the instructor was assigned by the faculty and the students self-registered the subject before the trimester commence.

The research framework of this study is illustrated in Fig. 3. This study is to incorporate CA into undergraduates' mathematics learning in the topics of probability with three objectives and three research questions as mentioned in the Introduction. They are going to answer by the result for achievements, attitude and perceptions measured by quantitative methods using the instrument of Probability Achievement Test (PAT), Probability Attitude Inventory (PAI) and Questionnaires on the Students' Perceptions on the Use of Conversational-based Agent in Learning Mathematics (SPCA). Whereas the qualitative methods collect data on students' attitude and perceptions through journals and interviews provides insight to the learning process and they complement the quantitative findings.

Furthermore, the quantitative research design of this study is displayed in Table 1. Due to the groups were formed before the study was conducted, henceforth, the randomization was difficult or impossible to implement, thus the non-equivalent group design with pre-test ad post-test was applied. As the study is to incorporate the CA into undergraduate mathematics learning, thus, the independent variable was the instructional approaches. The conventional instructional approach, which is the current practise at the research university, was applied to control group (CG). Meanwhile, the CA approach was applied to experimental group (EG). In this study, the primary dependent variables were the achievement and attitude in mathematics (or more specifically Probability as

Table 1. Quantitative research design

Group	Pre-intervention	Intervention	Post-intervention
Control Group	Pre-PAT and Pre-PAI	Control Treatment of conventional approach	Post-PAT and Post-PAI
Experimental Group	Pre-PAT and Pre-PAI	Experimental Treatment of CA approach	Post-PAT and Post-PAI

the study was focus on the topics of Probability). Therefore, both PAT and PAI were administered to both CG and EG before and after the intervention course.

4.1 Research Instruments

There are three main instruments, which are Probability Achievement Test (PAT), Probability Attitude Inventory (PAI) and Questionnaires on the Students' Perceptions on the Use of Conversational-based Agent in Learning Mathematics (SPCA) in this study but the first two are the primary instruments.

4.1.1 Probability Achievement Test

An achievement test is a test designed to "measure an individual's current proficiency in given areas of knowledge or skill" that could "provide information about how well test takers have learned the material introduced in school" [33]. Probability Achievement Test (PAT) is an instrument designed to investigate the first research objective. It is a self-designed test due to there is no a standardized test to the incorporates topics. Hence, there is a necessity to design this test in order to ensure the content validity. It is a formal pencil-and-paper test consists of 3 problem-solving questions that was conducted in a group as this way was time efficient and had high response rate [34].

The test was sent for validation for its relevance and concordance with the syllabus by five experienced mathematics lecturers who have an average of 22 years of teaching experience in the researcher's university. Besides, it was vetted in terms of language by an English lecturer who has more than 20 years of teaching experience. Additionally, the data collected was tested for reliability using Statistical Package for Social Science (SPSS) version 26 by compute the Cronbach's Alpha. The computed Cronbach's Alpha was 0.738 which implies that PAT is reliable as Fraenkel and Wallen [30] mentioned that an instrument with the value of 0.70 and above is reliable [29]. Indeed, the computed alpha value indicated that PAT has internal consistency, particularly, PAT is reliable in measuring students' knowledge and their ability in problem solving.

4.1.2 Probability Attitude Inventory

Attitude is "one's persistent predisposition to feel, act, or think either favorably or unfavorably toward a person, an object, or an idea" [35] at which their research was on students' feelings or opinions toward the subject of probability through questionnaire

Table 2. Examples of changes of 'Mathematics' to 'Probability'

Mathematics and science attitude inventory/attitudes toward mathematics instrument	Probability Attitude Inventory (PAI)
I enjoy talking to other people about **Mathematics**	I enjoy talking to other people about **Probability**
It scares me to have to take **Mathematics**	It scares me to have to take **Probability**
It is important to know **Mathematics** in order to secure a good job.	It is important to know **probability** in order to secure a good job

too. Probability Attitude Inventory (PAI) is an instrument to measure the students' feeling towards Probability through adapted questionnaire used to investigate the second research objective. This questionnaire was conducted in group similar as PAT but in an online survey form.

PAI is an adaptation due to the procedure to design a questionnaire is complex that involves many considerations [34]. Moreover, as the instrument to measure attitude to reflect the attributes accurately is structurally complex, it is sensible to adapt an existing measure if a suitable one exists [36].

PAI is adapted from *The Rochester Institute of Technology's Mathematics and Science Attitude Inventory*, an instrument used in Project EDGE [37] and *An Instrument to Measure Mathematics Attitudes* by Tapia and Marsh [38]. Since this study involved Probability, only the statements measure the attitude towards mathematics from *The Rochester Institute of Technology's Mathematics and Science Attitude Inventory* were chosen to compared with *An Instrument to Measure Mathematics Attitudes*. The statements were compiled after remove the similar statements from both sets. PAI was finalized after the discussion with the experts in mathematics education research and the English lecturer who had done the validation of PAT and the word of "Mathematics" was changed to "Probability" to make the statements relevant to this study. Table 2 shown the example of the changes.

4.1.3 Questionnaires on the Students' Perceptions on the Use of Conversational-Based Agent in Learning Mathematics

According to Mclntyre [39], questionnaire is a tool that can also elicit specific information about attitudes or perceptions of the respondents at which observational techniques may be difficult to assess these variables [39].

The questionnaire on students' perception on the use of conversational-based learning agent (SPCA) is an online questionnaire administered in group that is use investigate the third research objective, i.e. to evaluate students' perception on the use of conversational-based learning agent. The SPCA was an adaptation from [40–42] in the same way as PAI and with the same reason of adaptation as PAI.

Table 3. The computed Cronbach's alpha value and its interpretation

Instruments	Cronbach's alpha	Interpretation
PAT	0.738	Reliable
PAI	0.923	Excellent
SPCA	0.946	Excellent

4.2 Reliability and Validity of Instruments

Reliability is a statistical measure to evaluate the degree that a test consistently measures whatever it is measuring, while, validity is referring to "the degree to which a test measures what it supposed to measures and, consequently, permits appropriates interpretation of scores" [33]. In order to ensure the interpretation and the inferential of the data collected from any study are meaningful and valuable, the instruments must be both reliable and valid as described by Gay et al. [33].

Henceforth, all the research instruments were sent for validation for its relevance and concordance with the syllabus (for PAT) and for the clustering of categories (for PAI and SPCA) by five experienced mathematics lecturers who have an average of 22 years of teaching experience in the researcher's university. Besides, the instruments were vetted in terms of language by an English lecturer who have more than 20 years of teaching experience.

Additionally, the instruments were tested for reliability and validity using Statistical Package for Social Science (SPSS) version 26. The reliability test of the instruments was done by compute the Cronbach's Alpha value and the result are displayed in Table 3. The interpretation of Cronbach's Alpha values according to Fraenkel and Wallen [31] is shown in Table 3 as well. The computed Cronbach's Alpha value for each instrument not only implies each instrument is reliable, indeed, the it indicates that every instrument has internal consistency, particularly, each of them is reliable in measuring each variable.

Furthermore, the validity test of the instruments (PAI and SPCA) was done through exploratory factor analysis using principal component analysis extraction and Varimax rotation. Each statement of the instruments is remained if the factor loading is 0.50 or above.

The rotation solution yielded three interpretable factors for PAI, which are students' attitude towards the usefulness of Probability, students' interest in Probability, and students' self-concept in Probability. Meanwhile, the rotation solution yielded four interpretable factors for SPCA, which are the CA Usage, students' attitude towards learning Probability when using the CA, how the CA helps students understand probability concepts, and students' confidence in problem solving with or after the use of the CA.

5 Conclusion

This paper has presented the research framework based on Vygotsky theory and the research design that used mixed-method approach with three main instruments and convenient samples. The reliability and validity tests indicated that the instruments are

reliable and valid to further to data collection where the interpretation of data will be meaningful and valuable. This project is still on-going where data analysis is on progressing, hence, no data could be presented yet to conclude the study.

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Authors' Contributions. CPTan—research design, planning and management, system development, instruments preparation, data collection, data analysis and paper writing.
CKTan—review of research instruments and paper.
SHLau—review of research design and instruments.
ACKoo—review of research design and instruments.

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