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A comparative study of SAM and ADDIE models in simulating STEM instruction

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ABSTRACT

The study compared exhaustively the Successive Approximation Model (SAM) and Analyze, Design, Develop, Implement and Evaluate (ADDIE) model on the teaching and learning of Science, Technology, Engineering and Mathematics subjects in Ghana. We selected a sample of 30 student-teachers who offered Mathematics and Science in the distance mode of the University of Education, Winneba, Ghana in the 2018/2019 academic year. The first stage of the analysis compared the models separately within the Vygotskian framework using pre-post experiemtal design. The second stage made comparisons between and within the two models. The results of both stages showed that student-teachers preferred mostly SAM to ADDIE instructional models. There were not only consistently higher mean gains in the latter model, but the group averages of student-teachers in the post-treatment results also demonstrated clear improvements. Again, student-teachers showed tremendous improvements in the conceptual understanding of both models. However, the Successive Approximation Model recorded much more improvements in both pre-treatment and post-treatment results. It was therefore imperative to conclude that the Successive Approximation Model was more properly situated in the context of teaching and learning Mathematics and Science. We, therefore, recommended experimental explorations of SAM for STEM.

Keywords: Comparative study, SAM, ADDIE, simulating STEM, Vygotskian theory.

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INTRODUCTION

Instructional Design Central (2021) opines that instructional design models help instructional designers to make sense of abstract learning theory and enable the real-world application. Instructional design models organize and visualize learning theories and principles to guide instructional designers through a learning development process. Instructional design models can be considered a framework to develop learning materials. The common instructional models are action mapping, Learning Circle Framework, Merills' First Principle of Instruction, Gagne's nine events of instruction and Bloom's taxonomy. The rest are the Dick and Carey Model, Kemp's Instructional Design Model, Kirkpatrick's Four Levels of Training Evaluation, Successive Approximation Model (SAM) into Analyze, Design, Develop, Implement and Evaluate (ADDIE).

Despite the numerology of schools of thought and different instructional models can be customized in the simulation of Science, Technology, Engineering and Mathematics (STEM) domains that mainly intertwine behaviourism and constructivism within the frameworks of Vygotskian theories (Marshavkiy, 2014). Research acknowledges this yawning gap among student-teachers with respect to applying Vygotsky's theory in contexts (Reiser and Dempsey, 2013; Essel et al., 2016). It is even worst when integrating SAM into ADDIE instructional models in the teaching and learning of STEM subjects. This stems from the fact that student-teachers seemingly lack knowledge and skills of simulating teaching and learning of STEM in classroom interactions (West African Examinations Council, 2016).

It has been discovered that SAM is not the first learning design methodology to challenge ADDIE, but it is one of the most popular. The biggest difference is that SAM is an agile method, which allows multiple steps to take place at once while ADDIE is linear and often requires one step to be finished and reviewed before moving forward (E-Learning, 2021). This allows student-teachers to perform multiple tasks at the same time at the same place. It reduces cost, space and as opposed to ADDIE (E-Learning, 2021).

Theoretical framework

Zone of Proximal Distance (ZPD) was developed by Lev Semenovich Vygotsky in the late 1920s to focus not only on the completed level of development (the stage of development, where the learner can solve the problem independently) but also on the expected level of development (the learner solves a problem with the help of an expert) (Vygotsky, 1978; Fiorani, 2012). This difference requires adults, teachers and experienced peers to provide interesting and culturally meaningful problem-solving tasks that are slightly more difficult than what the learners do alone. Such a scaffolding experience can ensure that learners work either with one another, more competent peers, teachers, or other adults to accomplish these tasks. In such simulating situations, learners will most likely be able to solve the same tasks individually on subsequent higher tasks (Bartolini Bussi and Mariotti, 2016).

Again, simulation is a unique learning environment that allows student-teachers to experience and forecast critical care intervention strategies using ZPD (Vygotsky, 1978). However, it is not well examined and incorporated into the teaching and learning processes, particularly in the fields of STEM fields (Bartolini Bussi and Mariotti, 2016). In Ghana, studies (West African Examination Council [WAEC], 2016) have reiterated sound simulation approaches in boosting academic achievements of STEM subjects. Instructional models, such ADDIE and SAM can contribute significantly to the progress of STEM in the classroom (Salas, 2013; Marshavkiy, 2014).

In addition, Vygotsky acknowledges that elementary behaviours are primarily biological, and the higher psychological functions in STEM domains are sociocultural (Fiorani, 2012). This dichotomy of thoughts requires comparisons of the SAM and ADDIE models (Marshavkiy, 2014). If this is fully incorporated and implemented into the teaching and learning of STEM domains, the idea that a child should wait until he/she reaches certain developmental levels in order to learn would be non-existent. This is because basic school children constantly and continuously interact with experienced people and peers that help them to internalize the STEM processes as part of the child's independent developmental achievements.

Furthermore, Vygotsky's four phases of development have not been adequately exposed to student-teachers in the teaching and learning of STEM subjects (Matusov, 2015). In Vygotsky's four-phase model of the stages of human development, the first stage explains a natural developmental level, where learners naturally create associative and conditional reflexive connections through attention, interest and memory. The second stage provides connections between concrete representations of concepts and new abstract understandings. The third stage makes effective use of symbols and tools in constructing knowledge, and the fourth stage frees children from external signs and symbols. This stage allows children to internalize the processes, and use inner schemes and signs (Bartolini Bussi and Mariotti, 2016).

There is no gainsaying that ADDIE and SAM simulation models should be explored in the teaching and learning of STEM. As Matusov (2015) puts it: 'the purposes of teaching and learning are not just for eliminating gaps between less and more capable learners. Eliminating gaps is both impossible and undesirable due to the nature of human consciousness.' This means because human consciousness is presumably opaque and not potentially transparent, simulation is the best strategy to objectively forecast and address classroom interactions with STEM subjects.

ADDIE and SAM Instructional Models in Vygotsky's framework

The ADDIE was produced alongside other traditional instructional design models to form a basis for real-world working experiences in teaching and learning (Sallas, 2013).

In Figure 1, the 'analysis' describes the task, skills, knowledge and characteristics of pupils that lead to the specifications of perspectives and preferences. The 'design' determines the media and technology that suits the specification of the instructional activities. The 'develop' fashions out lesson plans, instructional materials, media, exercises and tests that lead to the specification of planning activities. The 'implement' setups up facilities and conducts training facilities, and the 'evaluate' determines learning modes, assessment tools, learners' feedbacks, learners' outcomes, programme improvements and learning reviews (E-Learning, 2012). Even though very fundamental, the model alone is deficient on grounds of its rigidity, time consumption, linearity and inadequacy of simulation experiences. For instance, the hierarchical steps cannot allow simulation. So, one requires many assumptions, and cannot forecast learning outcomes (E-Learning, 2012; Salas, 2013: E-Learning, 2021).

While agreeing that ADDIE is probably the most well-

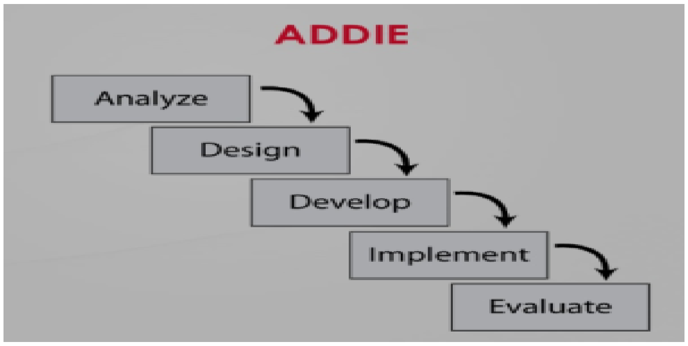

Figure 1. ADDIE instructional design model. Source: Salas (2013).

known model for designing teaching and learning, and has proven probably its popularity over time (Salas, 2013), SAM is an emerging plausible alternative model. Created by Allen Interactions Inc., SAM offers repeated small steps of iterations that address the common challenges of rigidity, time, linearity and stability when using ADDIE (Allen, 2012; E-Learning, 2014; Allen Interactions, 2016). In Figure 2, SAM is not only recent and modern; it is also faster rapid, repetitive, continuous, and more effective and efficient operations in yielding results successively closer to the desired equilibrium or steady state (E-Learning, 2014; Marshavkiy, 2014).

Quite apart, SAM fits well with ZPD's framework as the processes are iterative and interactive as one progresses from the early evaluation phase in SAM1 in order to allow for changes, modifications and reinforcements. This then invites collaboration of ideas, opinions, experiences, knowledge, task definitions, decision-making, documentation and skill mastery during classroom interactions of STEM subjects (Marshavkiy, 2014). Again, unlike ADDIE's five big sequential steps, SAM is much more a cyclical process that can be rescaled and extended to SAM2 (Allen interactions, 2016). The three main cyclical iterations of SAM1 steps (analysis, design and development) afford the primary iteration, ideas and assumptions to be discussed, prototyped, and tested early. These ensure the efficiency and effectiveness of any learning outcomes. If the instructional process is much more complex and unachievable, the instructor can proceed to SAM2 (Essel et al., 2016; ELM Learning, 2020).

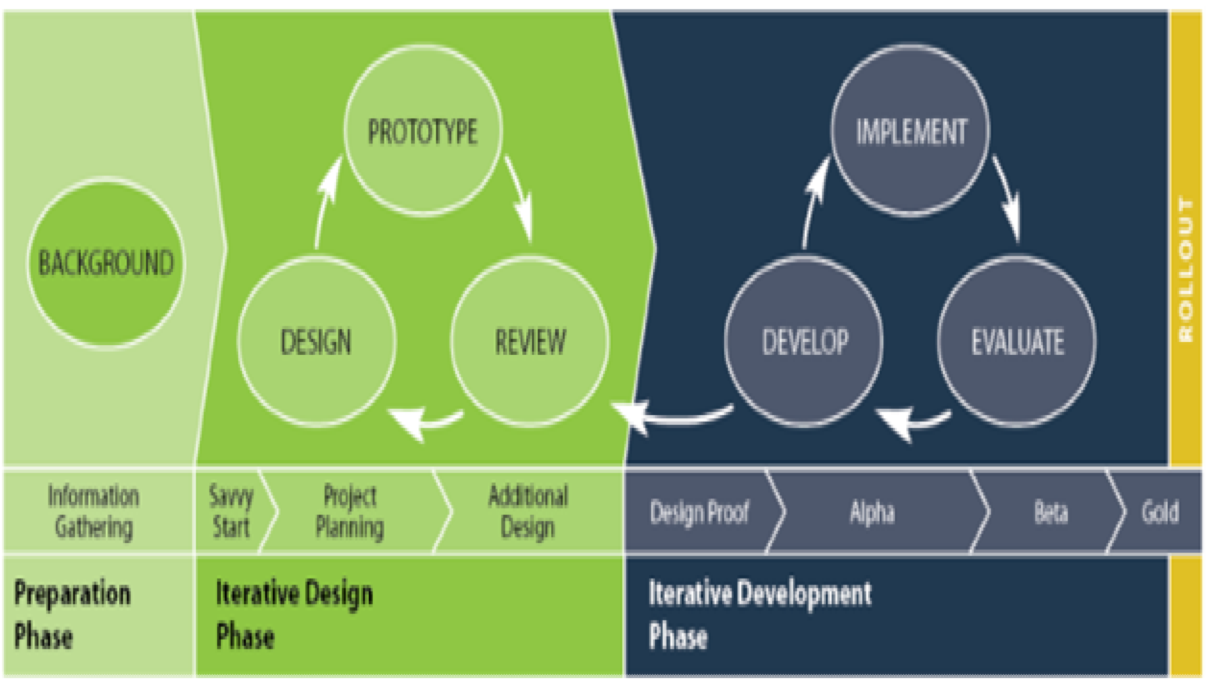

Figure 2. SAM instructional design model. Source: Allen Interactions Inc (2016).

In SAM2 iterations, multiple flows are much more iterative and simulative, formative and summative, collaborative and teamwork, efficient and effective, resourceful and creative, and manageable and time-bound in the eight iterative steps spread across three phases (preparation, iterative design and iterative development) (Marshavkiy, 2014). In the preparation phase (gathering information and savvy start), student-teachers gather background information and savvy start in order to brainstorm, review the information and create initial prototype ideas.

The iterative design phase (project planning and additional design) initially develops, evaluates and revises the prototype, and the iterative development phase (design proof, alpha, beta and gold) develops, implements and evaluates the proof, alpha, beta and gold cycles in multiple iterative ways (Allen Interactions, 2012; Shinde, 2017).

Even though SAM simulations equally encounter challenges that border on over-emphasis on human inevitability to mistakes and unaccountability to risks, they can be continuously modelled multiple statistical methods (Matusov, 2015; Allen interactions, 2016; Bartolini Bussi and Mariotti, 2016). Anku (2013) argues that the need for such practical models builds conceptual understanding. Learners are not only active participants but also fast grabbers of concepts. The theory was therefore developed to answer the following questions:

1. How were student-teacher's performances in the two instructional models before and after treatments? And how were student-teacher's conceptual understanding of SAM and ADDIE models before and after treatments of the STEM subjects?
2. **A Hypothesis**: Was there any statistically significant difference between the post-treatment test scores at all and which model was more statistically significant?

MATERIALS AND METHODS

In order to answer the research questions, the sequential embedded method design, in which qualitative data set provided a supportive secondary role to quantitative data (Cohen et al., 2011).

In Figure 3, the study employed a qualitative Likert scale to test the theory of Vygotsky's ZPD that predicts student-teacher's achievement in mathematics and Science using SAM over ADDIE models. A secondary quantitative closed-ended construct in Science and Mathematics further justified the conceptual understanding of the student-teacher in SAM over ADDIE models. These two methods provided supports to each other (Gray, 2014).

Out of the 30 student-teachers sampled from the Institute of Distance and E-learning, University of Education, Winneba, 20% were female and 70% male; 10% were teaching lower primary, 20% upper primary, 30% junior high school and 40% senior high school; and 60% specialized in Mathematics, 30% Science and 10% other disciplines. The sampling procedure purposively targeted only student-teachers who taught any STEM disciplines in the basic schools (Gray, 2014).

On the analysis of the qualitative data, only four student-teachers were interviewed intensively on the student-teacher's preferences of the two instructional design models. On the analysis of the quantitative data,

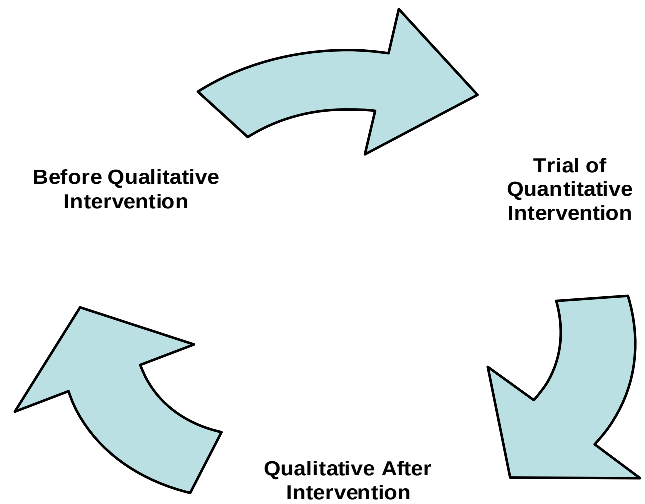

Figure 3. Sequential embedded design. Source: Creswell (2014).

the researchers explored student-teacher's preferences for ADDIE (that is, control model) and SAM (that is, experimental model), and the differences were statistically compared with the t-test using the SPSS. Since the data contained categorically independent variables and continuous dependent variables, the researchers consciously removed likely covariates to ensure internal validity and reliability of the findings (Creswell, 2014).

RESULTS

Research question 1: How were student-teacher's performances in the two instructional models before and after treatments?

The effect of ADDIE and SAM instructional models on students' performance in both mathematics and science was determined using descriptive statistics of the pre-test and post-test scores of the experimental and control groups' performance. Table 1 shows the mean, standard deviation, and mean gain for SAM and ADDIE models conducted before and after treatments.

Table 1 shows that SAM model had pre-treatment and post-treatment mean scores of 22.97 (SD = 6.66) and 30.17 (SD = 6.81) respectively. In the table, there was a massive mean gain of 7.20 after using the SAM instructional model in the lesson delivery and the interactive learning setting. More elucidating is achieving a group average of 30.17 in the post-treatment test compared with 22.97 in the pre-treatment test to demonstrate a clear improvement in the SAM model. However, the relatively larger standard deviation (6.81) was recorded in the post-treatment test as compared to that of the pre-treatment standard deviation (6.66). This

Table 1. Effect of SAM and ADDIE models before and after treatments.

Group	N	Pre-treatment mean	Post-treatment mean	Mean gain
SAM	30	22.97 (6.66)	30.17 (6.81)	7.20
ADDIE	30	22.87 (6.75)	26.84 (5.59)	3.97

shows relatively wider variability in the scores of the individual student-teachers in the SAM model as an instructional approach.

On the other hand, however, the ADDIE model recorded pre-treatment and post-treatment mean scores of 22.87 (6.75) and 26.84 (5.59), respectively. There was equally an appreciable mean gain of 3.97. That notwithstanding, there was also an increase of performance to an average of 26.84 in the post-treatment test from 22.78 in the pre-treatment test. Even though there was an improvement, it is crystal clear that this improvement was not as large and significant as was in the ADDIE model.

Again, contrary to the results of the SAM model, a smaller standard deviation (5.59) was discovered in the post-treatment as compared to the pre-treatment standard deviation (6.75) in the ADDIE model. This interesting outcome was explained by the high familiarity of the ADDIE model among student-teachers over the years.

Research question 2: How were student-teacher's conceptual understanding of SAM and ADDIE models before and after treatments of the STEM subjects?

The effect of instructional models on students' conceptual understanding in Mathematics and Science was determined using descriptive statistics of the pre-treatment and post-treatment responses of the SAM and ADDIE models. This determined the levels of their conceptual understanding in Mathematics and Science. Table 2 shows the results of both models conducted before and after the treatments.

Table 2. Conceptual understanding in SAM and ADDIE models.

Group		N	NU	PU	U
SAM	Pre-treatment	30	18 (68%)	7 (22%)	5 (10%)
	Post-treatment	30	4 (12%)	11 (36%)	16 (52%)
ADDIE	Pre-treatment	30	26 (85%)	4 (15%)	0 (0%)
	Post-treatment	30	16 (52%)	10 (35%)	4 (13%)

Key: NU: No understanding, PU: Partial Understanding, U: Complete Understanding.

In Table 2, it was discovered in the pre-teat test that 68% of the student-teachers demonstrated no understanding, 22% showed partial understanding and 10% showed a complete understanding in the SAM model. In the post-treatment, 12% demonstrated no understanding, 36% demonstrated partial understanding and 52% demonstrated a good understanding of the SAM model in the teaching and learning of mathematics and Science. When it came to using the ADDIE model, a woofing 85% demonstrated no understanding, and only 15% demonstrated partial understanding. No student-teacher demonstrated a complete understanding of using the ADDIE model to teach and learn Mathematics and Science. However, after the treatment with the ADDIE model, 52% demonstrated no understanding, 35% demonstrated partial understanding and 13% demonstrated a complete understanding of the model.

These results generally showed tremendous improvements in the conceptual understanding of the student-teachers in using both SAM and ADDIE models. However, the SAM model recorded much more improvements in the post-treatment. For instance, in the SAM model, the student-teachers attained a complete understanding of 52% after the implementation of the post-treatment test as compared to the pre-treatment score of complete understanding of 10.00%. This positive and significant effect of the SAM model was properly situated in the teaching and learning of Mathematics and Science.

On the other hand, even though there was an improvement in the conceptual understanding in the ADDIE model, about 85% demonstrated no understanding in the pre-treatment test compared to 68% of no understanding in the SAM model. Again, 15% demonstrated partial understanding in the pre-treatment of the ADDIE as compared to 22% in the SAM model. No single student-teacher demonstrated a complete understanding in the ADDIE as against 13% in the SAM model. These results revealed that there is a quite remarkable improvement in the conceptual understanding of student-teachers in the SAM model.

A Hypothesis: Was there any statistically significant difference between the post-treatment test scores at all and which model was more statistically significant?

There was a statistically significant difference between the post-treatment test scores of students exposed to SAM model (M = 30.17, SD = 6.81) and ADDIE model (M = 26.84, SD = 5.59), [t = (91) 2.54, p = 0.012] at 5% level of significance. There was also statistically significant difference between the conceptual understanding of student-teachers in SAM model (M = 18.08, SD = 3.66) and ADDIE model (M = 15.86, SD = 3.33), [t = (91) 2.71, p = 0.0188]. Here, it was discovered that in both cases, the means of the SAM models were always greater than that of the ADDIE model.

DISCUSSION

Research question one: How were student-teacher's performances in the two instructional models before and after treatments?

The study set out to find the effect of SAM and ADDIE instructional models on the performance of student-teachers in Mathematics and Science. Positive effects were felt in the teaching and learning of Mathematics and Science. The ADDIE model presented a general and generic structure for the student-teachers and was used as the basic unit to help them propel to the SAM model (Salas, 2013). Based on research evidence (Allen Interactions, 2012; E-Learning, 2021), it appears that the ADDIE model provided a sound and solid foundation upon which the SAM model was built. The findings with respect to research question one were positive. This means the performance of the student-teachers exposed to the use of the SAM instructional model was better than that of the ADDIE model in teaching and learning Mathematics and Science. This presupposes that the student-teachers can change teaching and learning strategies as required by the situation.

Research (Allen Interactions, 2012) opines that recent educational applications of Vygotsky's work are useful in explaining teaching, learning and instruction principles. The theory allows instructional situations that advance learners toward higher levels of understanding (Essel et al., 2016). The ZPD provided instruction that spans the three phases in which student-teachers concurrently advanced in both models (E-Learning, 2014; ELM Learning, 2020). Moreover, settings for the teaching, learning and instruction were considered in terms of social interactions that supported realistic settings for student-teachers to explore, direct their learning, and work in collaboration with one another (Shinde, 2017). These models reduced emphasis on teacher-directed learning, as well as drill-and-practice routines. These provided student-directed exploration, guided learning, and cooperative learning through peer interactions.

In addition, the findings supported and confirmed the research hypothesis that there is a statistically significant difference in performance between students exposed to the SAM model and the ADDIE model for teaching, learning and instruction of Mathematics and Science. The findings support the argument of Allen Interactions (2012) the SAM model process is iterative as its development done in small steps with frequent early evaluation allows for changes that can be modified when changes cost the learner least; the model process supports collaboration in order to effectively take advantage of the ideas, opinions, experiences, and knowledge of team members, through clear task definitions, decision-making, documentation, and skill mastery; the model process is efficient and effective in actively addressing student-teacher's needs as they master skill sets as varied and rich involvement from different subjects makes for a better learning environment; model process is manageable as it allows for the completion of proficiencies on time. These benefits (of SAM) are more efficient and effective processes and superior learning experiences in less time (Allen Interactions, 2012; ELM Learning, 2020).

Also, the findings reaffirm the studies of Marshavikiy (2014) where scores between the pre-treat and post-treatment for each of the teaching methods were thoroughly examined. The results of their repeated measures ANOVA test indicated highly significant differences between the teaching methods. The multiple comparisons revealed that student performance improved under the lecture method as compared to the lecture/discussion (p = .010) and team project methods (p < .0001). Marshavikiy (2014) suggested that faculty should attempt to include constructive, active teaching methods in their courses whenever possible. These must be structured, controlled collaboration and sequentially iterative (i.e., SAM) as opposed to uncontrolled, unstructured experiences and non-routine processes (i.e., ADDIE). Most student-teachers prefer to be active in their teaching and learning process. The active and collaborative SAM models examined are not only desirable to many student-teachers but produce significant improvement learning outcomes.

Research question 2: How were student-teachers' conceptual understanding of SAM and ADDIE models before and after treatments of the STEM subjects?

The findings with respect to research question two were also positive. The conceptual understanding of student-teachers in the SAM model alone did improve significantly than those exposed to the ADDIE model alone. This also positively affected the performance of the SAM model as the quantitative questions in the post-test were conceptually based (Allen Interactions, 2016). One needed to have a strong and formidable conceptual understanding before he/she could tackle such questions. These outcomes could be explained by Allen (2013) that the process was iterative as being done in small steps with a frequent evaluation that allows for changes at regular times; the process supported collaborations, allowed for the flow of ideas, opinions, experiences, and knowledge while avoiding bureaucracy and indecision; the process was efficient and effective and produced quick and faster outcomes; and the process manageable and allowed for timely completion within the ZPD criteria.

Furthermore, there were statistically significant differences between the post-treatment scores in both SAM model (M = 18.08, SD = 3.66) and ADDIE model (M = 15.86, SD = 3.33) at the set 5% level of significance. There were also statistically significant differences between the conceptual understanding of student-teachers in both SAM and ADDIE models. Even though the differences were much more recorded in SAM than ADDIE, Allen (2016) offered SAM as an alternative to ADDIE utilizing similar tasks, but without the traditional step-by-step requirements. When it comes to evaluating which of the two models is a better fit for STEM, it boils down to the nature of the content of teaching and learning. Because the teaching and learning of STEM embrace agility in theory and practice, the SAM model was most appropriate in even incorporating more iterative development practices into the mix. However, in cases where the content did not encourage rapid feedback and flexible processes, the researcher adopted ADDIE's waterfall model (Salas, 2013).

Shinde (2017) revealed that the similarity in both models is based on iterative process. But the differences lie in the history, the process, time and school of thought. In history, ADDIE has a long-standing history but SAM is a new model. In process, ADDIE is a linear process while SAM is a cyclical process. In time, ADDIE is slower and SAM is faster, and in school of thought, ADDIE puts too much emphasis on process and perfection while SAM is focussed on learner experiences, engagement, and motivation. Even though both models are unique, the preference for ADDIE is less than SAM. Certainly, the results justified SAM over ADDIE.

CONCLUSION

We, therefore, concluded that the use of the SAM model as an instructional approach in an interactive learning environment had proven to be more efficient and effective in the teaching and learning of STEM. The findings revealed that student-teachers learned better in the SAM model and a greater number of student-teachers had made meaningful contributions during the classroom instruction. Also, student-teachers developed more interest when they interacted with each other. Moreover, following the analyses of the post-treatment results, it can be unarguably concluded that the SAM instructional model far exceeded the outcomes of the ADDIE instructional model. Therefore, in enhancing the performance of student-teachers in STEM in general and Mathematics and Science in particular, the results of lessons should not just be hierarchically sequenced but also cyclically iterated.

Again, the effect of the SAM instructional model on student-teachers' conceptual understanding was greatly improved. At all material moments, the treatments clearly showed positive effects of the model on student-teachers' conceptual understanding of STEM. It was, therefore, more appropriate to conclude that, in teaching and learning STEM, student-teachers should rely on SAM in the teaching and learning process. Occasionally, however, they can invite ADDIE especially during introductions and conclusions of lessons.

Finally, the battle between the two models still rages on between perfectionists who love the ADDIE model and the modernists who prefer the SAM (ELM Learning, 2020). We, therefore, concluded that the scope, content and context of a particular STEM subject must dictate to the student-teacher the type of model to adopt.

RECOMMENDATIONS

We have consequently recommended that experimental explorations of SAM models for STEM instead of the general instructional methods and strategies. Simulation models deeply explore the efficacy and effectiveness of teaching and learning of STEM domains. Student-teachers should be encouraged to use SAM instructional models in an interactive classroom. The model improves student-teachers' conceptual understanding of STEM, especially in Mathematics and Science.

As a matter of policy and practice, we also recommended that stakeholders should organize routine training workshops, conferences, seminars and webinars on SAM models. This will help prepare student-teacher adequately to consolidate their knowledge and improve on their professional practice. Going forward, the SAM models should not only be reserved for STEM, Other course domains can adopt them to enhance research, policy and practice. If comprehensively embraced across disciplines, its potential to modify and change classroom instruction is a matter of time.

Studies (E-Learning, 2021) recommend that we end the war between SAM and ADDIE and rather localize the context of the classroom interaction of STEM subjects. This is because no one is using the 1975 version of ADDIE anymore, and many designers have adapted the ADDIE model into something more flexible and even iterative like SAM. We, therefore, recommend that student-teachers take good decisions when applying the SAM model. This may avoid duplication of ADDIE in another context and not strictly applying SAM in the way the processes ought to go.

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